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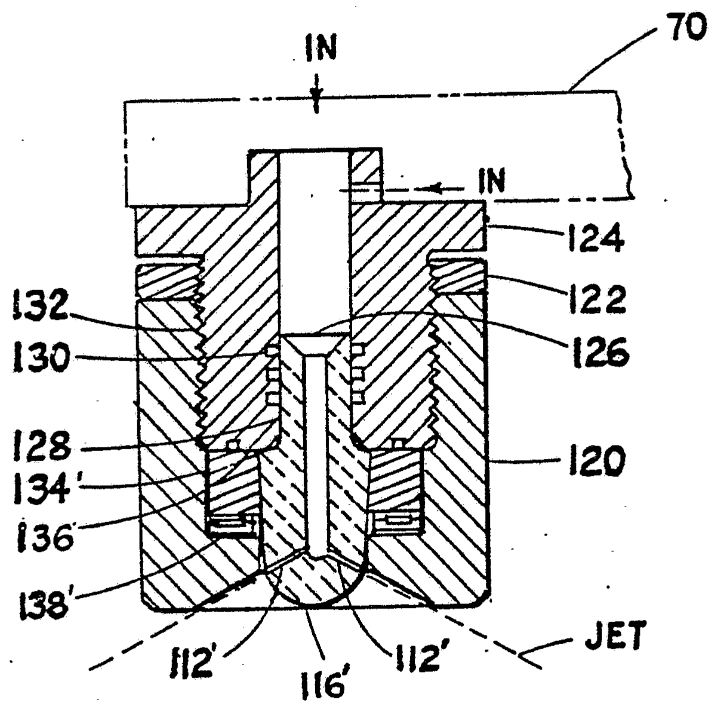
(57) Abstract

Hydrojet drilling means (10) and method are presented. This includes feed control of a self-rotating cutter having tangential acute angle jets (112). These acute angle, high velocity jets (112) provide deeper penetration, enhanced by successive impingements on rock increments (Figure 5A). At 10,000 psi., these pulsations amplify conical slot penetration to exceed prior art for certain strata. Lateral feeding of cutter jets shears rock subjecting it to tensile failure. Linear or rotary advancement of the cutter causes conical slot intersecting, releasing unsupported fragments. Energy expended per volume removed is greatly reduced. Hydrojet drilling means (10) and method include delivery of a recyclable, filtered fluid supply to a downhole means of pressure intensification, when needed. A dynamic stabilizer (14) controls feed and direction of the drill head (12). In operation, the drill head (12) with its rotating, multiple jet cutter is swung, rotated or linearly fed as it advances spirally or step-wise. Rapidly displaced chips are mucked by means of prior art.



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BACKGROUND OF THE INVENTION

HYDROJET DRILLING MEANS AND METHOD

Field of the Invention

The present invention relates to drilling and cutting means that utilize direct, pulsating, fast-flowing, tightly focused streams of fluid such as water under controlled feed conditions.

Background of the Prior Art

Waterpower is well known as a means of spraying, eroding, shearing, fragmenting and conveying materials. It is also well known for its conversion to electrical, heat and mechanical energy. For drilling, severing and mining, its main use has been for water cannon fragmentation, slotting (kerfing), conveyance of material and jet assistance of plows, shears, picks and other mechanical cutters. Mechanical means have been reaching practical technological, size, complexity, power, utility and operational limits, particularly when optimum recovery is needed along with minimum environmental disturbance to obtain relatively inaccessible resources.

Much of the machine and system innovations and adaptations necessary for commercial hydrojet drilling and cutting applications remains largely unrealized. Beginning mostly in the 1970's, a substantial amount of research and development has been done. This research and development has greatly advanced the understanding of and the prospects for hydrojet drilling and cutting of various rocks and materials. However, the objectives of such research and development have differed. Cutter or jet designs, methods of feed and operating conditions have also differed. Significant findings, therefore, must be carefully evaluated for their emperical or relevant data. Furthermore, the design of cutters, their

their feed and their system operations during testing have had to be rudimentary in order to isolate significant findings. Investigations have included "low" operating pressures up to 20,000 psi. and "high" operating pressures of 50,000 psi. or greater, orifice design, attitude and stand-off, jet cohesion, feed rate, pulsation or amplification, high velocities (at or greater than the speed of sound in air at sea level), and specific energy per volume removed. Despite these efforts, the bridge between significant laboratory findings and the spectrum of commercial hand tool., machinery and system design applications remains mostly uncrossed.

A partial list of hydrojet research is referenced:

1. N. Brooks, PhD., Sc.(eng), E. ENG., E.H. Page, PhD.m, B.Sc.(mining), "Energy Requirements for Rock Cutting by High Speed Water Jets", Dept. Mining and Mineral Sciences, Leads Univ.,U.K. 1972 (energy, rock removal rates, jet traverse rates, high pressure jets).
2. J.H. Olson, PhD., "Jet Slotting of Concrete", Flow Research, Inc., U.S.A., 1974 (approx. weights of high pressure equipment, kerfing depths, advance rate, stagnation pressure).
3. Labus, T.J., Silks, W.M., "A Hydraulic Coal Mining Machine for Room and Pillar Applications", IIT Research Inst., USA(T.J.Labus); Goodman Equipment Corp., USA (W.M.Silks),1976.(total assembly equipment select.)
4. Summers, D.A., B.Sc., PhD. C.Eng., MIMM, D.J. Bushnell, PhD., "Preliminary Experimentation for the Design for the Waterjet Drilling Device", Univ. of Missouri-Rolla, USA, 1976 (cutting attitude to bedding plane, nozzle angles, rotational rpm feed rates, pressure, depth of penetration).
5. Labus, T.J., "Energy Requirements for Rock Penetration by Water Jets", IIT Research Inst., USA, 1976,(traverse rate, wall interaction, rock

characteristics, specific impulse, pressure).

6. Hilaris, J.A., Labus,T.J., "Highway Maintenance Application of Jet Cutting Technology", IIT Research Inst., USA (Hilaris,J.A.) and SCTRE Corp., USA (Labus,T.J.),1978(nozzle geometry, multiple pass cutting, comparisons with mechanical cutting).

7. Summers, D.A. and Lehnoff, T.F. and Weakly, L.A., "The Developmentof a Water jet Drilling System and Preliminary Evaluations of its Performance in a Stress Situation Underground", Univ. of Missouri-Rolla USA(Summers, D.A.and Lehhoff, T.F.), St. Joe Mineral Corp. USA(Weakly, L.A.), 1978.(high pressure rock drilling, penetration rates, rock stress)

8. Wolstead, O.M., Noecher, R.W.,"Development of High Pressure Pumps and Associated Equipment for Fluid Jet Cutting",McCartney Mfg. Co., Inc.

9. Cummins & Givens, SME Mining Engineering Handbook, Vol.I, 1973 (Sect. 11.0, Drilling Data and Standard Practices)

10. J.C. Bressee, Sc.D., J.D., G.A. Cristy, M.S.,W.C. McClain, PhD., "Some Comparisons of Continuous and Pulsed Jets for Excavation", Oak Ridge National Lab., USA, 1972.(specific energy of continuous jet for different rocks and slurry concentrations).

11. B. Grossland, M.Sc., PhD., D.Sc., F.I. Mech. Eng., F.I. Prod. Eng., J.G. Logan, B.SC., PhD.M, "Development of Equipment for Jet Cutting", Dept. of Mech. Eng., The Queen's Univ. of Belfast (Dr. Crossland), Coleraine Instrument Co., N. Ireland (Dr.Logan), 1972.(high pressure)

12. H.D. Harris, PhD., W.H. Brierly, "Application of Water Jet Cutting", Nat. Research Council of Canada, Div. Mech. Eng., Canada.(comparative costs of 3 arrays for kerfing, nozzle size, materials).

13. S.C Crow, P.V. Lade and G.H. Hurlburt, "The Mechanics of Hydraulic Rock Cutting", Univ. of Calif. USA,1974.(stand-off dist., pressure, rock permeability and porosity).

SUBSTITUTE SHEET

14. H. Hamada, T. Fukuda, A. Sijoh, "Basic Study of Concrete Cutting by High Pressure Continuous Water Jets", Kobe Steel Co., Ltd., Japan, 1974.(specific energy, nozzle size, pressure, compr.strength)

A substantial number of U.S. patents have been issued for various hydrojet applications, including:

3,318,213	3,424,256	3,853,186
3,141,512	3,554,301	3,857,449
3,285,349	3,650,338	3,888,319
3,396,806	3,834,787	3,908,045
3,677,354	3,567,222	4,241,796

In spite of laboratory and applied research and the issuance of patents for what theoretical advantages hydrojet drilling and cutting offers over prior art, only simple high pressure jets for severing, fragmenting, splaying and shearing assistance(for mechanical means) have entered the commercial field. There has been the tendency to use ever-higher pressures such as 50,000 psi. Although controllable in the laboratory or protected production line, practicable field applications dictate otherwise. Unreliability, high maintenance, short life, safety hazards, equipment size and complexity and high power and water needs all inhibit commercial applications and acceptance.

The present invention attempts to solve these existing problems by using a hydrojet cutter that operates at 10,000 psi., but no greater than 20,000 psi. and offers the cutting capacities of the substantially more high-powered hydrojet cutters by controlling the lateral shear movement of a 10,000 psi. hydrojet cutter in patterns that permit greater penetration and material removal with less energy required by prior art designs, depending on the strata. The rotating cutter jets conically penetrate and then intersect to free untouched fragments. The use of this multi-directional acute angle shearing technique gives much the same advantage as a sculpter or skilled log chopper using less energy.

DISCLOSURE OF THE INVENTION

Summary

Hydrojet drilling and cutting means and methods of feed are presented. These means comprise a base, at least one drilling head, and in a preferred embodiment exactly one drilling head coupled to the base. Stabilizing means are coupled to a variety of feed control means and both are coupled to the drilling head. A source of cutting fluid such as recyclable, treated water is supplied to the drilling head. Cutting fluid pressure means of intensification are coupled to the drilling head.

The base means comprise a structural means of support for alignment means of reference for feed controlling means, for fluid supply and mucking means, for power supply means and for systems deployment means.

A purpose of this invention in both its preferred embodiment and its alternatives is to provide hydrojet drilling and cutting means and feeding methods that are in their combined effect more efficient in the use of energy and cutting fluid in the penetration and volumetric removal of rock and other host materials than those of individual hydrojet drilling and cutting means and methods by prior art. Such efficiency is derived partly from the avoidance of counter-productive attributes of the prior art.

Another purpose of this invention is to provide means for effectively exploiting the inherent weaknesses of various host materials such as laminar structure, permeability, porosity, inelasticity, low bond strength and erosion resistance, low shear and tensile strengths and granular displacement.

Another purpose of this invention is to provide accurate control of the geometric patterns of cutting and hole alignmentduring advancement.

Another purpose of this invention is to provide a hydrojet drilling and cutting means and feeding methods that are more commercially acceptable for a wide range of applications.

Description of the Invention

The drilling head comprises a self-rotating, high pressure plenum defining structure coupled to a plenum body of the output plenum of the pressure intensification means in a substantially fluid type coupling to receive boosted pressure fluid from the intensification means. The interior surface of the high pressure plenum defining structure defines a generally axially symmetric plenum rotating about an axis. The output of the plenum defining structure comprises at least three flow lines with orifices, exactly three in the first example, disposed generally symmetrically at equal angles about the axis of the plenum. The orifice flow lines originate tangentially from the axially symmetric plenum in substantially the same relative orientation and exit at a downward acute angle of approximately 25 degrees in a first example from a plane perpendicular to the axis of the plenum. Pressurized fluid enters the tangentially disposed orifice flow lines to induce a rotational moment of the plenum defining structure and to provide successive hydraulic jet impingements in a pulse-like manner during cut and clear jet penetration and shearing from a plurality of directions as new rock or other material is exposed, cut and displaced. The exterior surface of the plenum defining structure is generally axially symmetric and is coupled non-rotatably with a generally axially symmetric internal retainer bearing.

A non-rotating housing means comprises an interior surface defining a female bearing structure which rotatably mates in a substantially frictionless coupling with an axially symmetric rotating internal retainer bearing. Rotational velocity controlling means of the non-rotating housing means are adjustably affixed to a plenum body external mounting means. The housing interior surface is rotatably coupled to the rotating internal retainer bearing means affixed to the plenum defining structure. Bearing frictional adjustments permit selected variations of rotational velocity of the plenum defining structure.

Housing guard and stand-off means are disposed around the exterior surface of the plenum defining structure extending in a circle below the lowest exposure of the rotating plenum defining structure but within a cone defined by jet stream angle extension. The housing means comprise a hardened nut which nut retains the assembly, permits frictional rotational speed adjustment, establishes a minimum jet stream stand-off distance and provides structural protection for the rotating plenum defining structure in a first example.

Labyrinth seals seal with low leakage at least certain of the rotating cylindrical bearing surfaces of the plenum body. The labyrinth seals in one example seal at least certain flat bearing surfaces of the internal retainer bearing means and the plenum body.

Matching bearing surfaces of the housing means and the conical bearing surfaces of the internal retainer bearing means may absorb and translate externally applied shock loads through the bearing surfaces to the base mounting surfaces of the plenum body.

In one embodiment the means of pressure intensification provided for the drilling means comprises a closed loop hydraulic double-acting intensifier system capable of boosting a low pressure, high volume cutting fluid supply to sustain uniform pressures of about 10,000 to 20,000 psi. A means of pressure intensification using one or more double-acting intensifiers comprises modified end caps or retaining structures shaped as a triangle to reduce the intensifier closed loop hydraulic system configuration circumferential size for confined areas.

The means of pressure intensification provided for the drilling means may comprise one or more open loop, stacked, positive displacement pumps serially boosting input cutting fluid supplied at low pressures to a uniform output pressure of 10,000 psi. at the plenum.

A variety of cutting motions for the drilling head are made possible by means of the dynamic stabilizer feed and control means which moves the drilling head in a generally circular pendulum arc, an elliptical pendulum arc or generally linear pendulum-like arc, which linear arc may or may not rotate, and other possible motions during shearing of selected materials. In operation, it is possible to pre-program certain selected arcs as part of the control system and when the cutting rate slows down, to switch to a different series of cutting arcs to adjust to strata conditions. The control system may comprise any of a number of micro-positioner computers available with logic accomplished by prior art computer circuitry or electronic circuitry.

In one example, the dynamic stabilizer means comprise a stabilizing means, and a plurality of separate control means for feeding and correcting the location of the drilling head. The control means comprise means for sequential horizontal feeding and vertical angular alignment thereby directly controlling the drilling head movement according to correction signals. The control means cause the drilling head axis to move in a general daisy pattern in a first example such as would be superimposed by the center of the drilling head on a plane perpendicular to the axis of the drilling head. The pattern may be altered by control regulating the speed and sequencing of drilling head movement.

The control means provide feeding and alignment adjustment in one example by employing inflators. The inflators receive programed and metered amounts of pressurized fluid as a function of photocell positions and signal transmittal means causing the inflators to react with the walls defining a drilled hole or slot. The inflators may be repeatably and variably inflated and are fabricated from a relatively tough, smooth, flexible fluid-tight material such as neoprene impregnated nylon scrim.

An alternate dynamic stabilizer means of control and feed of the drilling head position and rate is by reaction jets which receive programed and metered amounts of pressurized fluid as a function of photocell position and signals. The jet total impulse and fluid mass is capable of reacting effectively with the denser mucking fluid and the wall defining the drilled hole or slot.

In another example, the control and feeding means of the drilling head may be provided by pistons as part of the dynamic stabilizer means. The piston means receive programed and metered amounts of pressurized fluid or other power as a function of the photocell position and signals. The piston means exert force on the walls defining the drilled hole.

A separate water source is pumped from the settling pond at pressures of 200-500 psi. to the dynamic stabilizer means for feeding and alignment control in an example using jets for control and the fluid is metered through the control orifices to then contribute to the mucking supply. The separate water source may also be used to supply the inflators and pistons.

A plurality of controlled columnar light sources which may be lasers are coupled to a base and projected in a selected single direction parallel to each other to provide fixed references for drilling alignment control. The plurality of controlled columnar light sources may comprise leveling means adjustable for fixed horizontal positioning of the light sources perpendicular to the axis of drilled hole or slot. The plurality of controlled columnar light sources may comprise a leveling means adjustable for predetermined non-horizontal positioning of the light sources for reference in slant hole drilling. A plurality of controlled columnar light sources may comprise lowering means of the light sources as a reference to lower elevations while maintaining one only relationship of the fixed horizontal positions of the light sources with other fixed non-horizontal positioning of the light sources in the drilled hole.

Each columnar light source generates a light source parallel to that of each other columnar light source and shines on a coupled one of a plurality of matching photocells or arrays, one for each columnar light source. The photocell arrays are coupled by circuitry to the dynamic stabilizer reaction control means of the drilling head. The photocell arrays are positioned a sufficient distance above the mucking waterline in relative close proximity to the dynamic stabilizer. The control means utilize the columnar light sources and the plurality of matching photocell arrays to control orientation of the drilling head without creating cumulative errors because of independence of surface variations of the drilled hole or slot.

The control means include repositioning and relocation circuitry known to the prior art which permits programed sequencing and other control means to reposition and correct the drilling head during drilling pursuant to instructions from the control means. The photocell arrays that are matched and coupled to the columnar light sources generate signals as a function of where light is received on the photocell array, one cell activated by receipt of a matching columnar light input. The signal from the activated photocell is coupled to a corresponding control means which meters a specific amount of reaction fluid for control.

The mucking means comprises a plurality of lift pipes known to the prior art that extend to the bottom of the drilled hole. The lift pipes are comprised of water pipes combined with side-entering air injection tube means which induce a differential pressure for muck removal. A portion of the mucking fluid is derived from the cutting fluid passing through the drilling head for localized mucking enhancement where cutting takes place. The rate of lateral feed and drilling head advance is a function of the mucking rate efficiency of the lift pipes. Other sources of make-up fluid are derived from the dynamic stabilizer control fluid, from water pumped directly from the settling pond, and by random seapage from any aquifers encountered during drilling. A float valve means controls pond make-up water input and muck level. It should be noted that an invention as claimed herein includes the capability of using a plurality of lift tubes with pressurized air injection for the collection and diversion augmentation means of prior art means of blow out prevention which may be needed when drilling for oil and gas. Lift tube means in conjunction with pump-located relief valves divert excess pressurized material to storage.

Power means are coupled to pumps for delivery of cutting fluid to the drilling head means, water for the dynamic stabilizer means and mucking means, liquid and solid mixtures for hole casing means, and for coupling to power distribution means for light source reference means, and for electrical sensing, control and drive means of thesystem.

Continuous wall casing means comprise a plurality of radially and axially moveable segments capable of retaining the injection and pressure for rapid curing of chemical and shotcrete material during wall lining of the drilled hole. Wall casing means may intrude into the mucking area.

For certain applications, the drilling means may comprise a plurality of drilling heads, each drilling head including a separate rotating high pressure plenum defining structure. Alternately, the drilling means may comprise a plurality of rotating plenum defining structures within each drilling head structure , each drilling head structure utilizing a common high pressure plenum.

Industrial Applications

The hydrojet drilling and cutting means and methods of this invention in full or in part have applications for a wide range of industrial use. In particular, this refers to the adaptations of one or a plurality of drilling head means, plenum, cutting fluid intensification means, dynamic stabilization, control and feeding means, and alignment means for hand-held tools, machines and systems.

The industrial areas include surface and underground mining of coal and ore; oil, gas, steam and water recovery; road and airstrip resurfacing and treatment; shaft development; dry rock geothermal drilling; tunneling; descaling of boilers and boiler tubes; marine paint and fouling removal; trenching and mole boring for pipe and conduit emplacement.

The conditions for such applications refer to both direct and remotely controlled machines and systems.

BRIEF DRAWING DESCRIPTION

Figures

Reference is made to the following figures:

FIGURE 1 shows a side view of an example of drilling means;

FIGURE 2 shows enlarged lower portion of the drilling means;

FIGURE 2A shows a section view example of the intensification means;

FIGURE 3 shows a daisy pattern cutting example of the drilling head;

FIGURE 3A details an example of drilling means with reaction jets;

FIGURE 3B shows a drilling head swinging in a pendulum arc pattern;

FIGURE 4 shows an end view of jet flow lines;

FIGURE 5 shows a cutaway side view of the drilling head;

FIGURE 6 shows an example of inflators used for control and alignment;

FIGURE 7 shows one inflator with control and alignment means;

FIGURE 8 shows timed sequence of inflators controlling drilling head;

FIGURE 9 shows a side view of jet flow reaction control and alignment;

FIGURE 10 is a schematic diagram for dynamic stabilizer circuit;

FIGURE 11 shows positions of photocell array and light source;

FIGURE 3C top view shows spiral locus of each cutting jet while drilling head is laterally fed; side view shows spiral intersecting of multiple jets when drilling head is laterally fed;

FIGURE 4A shows an end view of alternate tangential orifice flow lines of plenum defining structure;

FIGURE 5A shows a cutaway side view of an alternate variation of the drilling head.

Detailed Drawing Description

Figure 1 shows a side view of drilling means and methods 10 in accordance with present invention and includes a drilling head 12 also known as cutting head 12, a dynamic stabilizer assembly 14, a pressure intensifier 16 also known as a pump 16, a plurality of air hoses 18 and lift pipes 20. The drilling head 12 cuts a hole which is filled with mucking water 22 and maintained at a level below waterline 195. A wall casing 28 may be formed to firm the sides during hole excavation. Drilling head coupling means 30 also known as a stringer 30 couple the drilling head to a base 54 or rig 54 located at or above the surface of the ground. A plurality of light sources 32 each transmits parallel columnar light references for corresponding photocell arrays 26 assembled above the waterline 195 to establish position and provide signals for metering control means coupled to the drilling head 12 for correction. The pre-programed control means meter pressurized fluid to provide stability and positioning means coupled to the drilling head 12 . In Figure 1 the controls 36 shown on a crawler vehicle at the surface but could be at any convenient place. A sleeve and collar arrangement 34 conventionally reinforces the hole entrance. The surface equipment on the vehicle also includes a compressor 38 powered by a generator 40. In this first example, a water pipe 52 from a diked settling pond 50 is coupled directly to pump 56 for mucking make-up water or jet supply to the alternative dynamic stabilizer 14. Mucking removes the mucking water 22. The mucking water 22 is pumped by surface pumps 44 through lift pipes and airlift 18 supplied by air compressor 38 back to the settling pond 50. Heavy particles precipitate in the settling pond 50. Water for cutting fluid from the settling pond 50 is pumped and filtered by a separator 42 which separates out all particles in excess of 15 microns. The surface pumps 44 pump cutting fluid through waterlines 46 to the rig 54 where cutting fluid additive 48 is proportionately added to the water.

Reference to Figure 2 and Figure 2A shows a more detailed view of the drilling head system. The drilling head 12 is coupled with a downhole fluid pressure intensification means 16 which may be a pump 16 which receives fluid from the stringer 30. Other cutting fluids than water may be utilized for select purposes. The input of the high pressure plenum 70 comprises a water feedline 68 coupled to the output of the pressure intensification means 16 in a substantially fluid tight coupling to receive high pressure fluid intensification means 16. The output of the plenum 70 is coupled to a plenum defining structure 116 comprising in this example, three orifice flow lines 112 (shown in Figure 4) disposed symmetrically about the axis of the plenum defining structure 116 at equal angles. The orifice flow lines originate tangentially from the plenum defining structure interior surface in substantially the same relative orientation about the axis. The orifice flow lines 112 exit at a downward acute angle from a plane perpendicular to the axis as shown in Figure 5.

Also shown in Figure 2 is a retainer block 72, which holds the parts together, limit switch control valves 74 which reverse the intensifier, a control valve 76 which directs fluid flow, the stringer 30 which includes the water feedline and the means of suspension, and the pump 16.

Figure 2 shows a double acting pressure intensifier means for boosting pressure to approximately 10,000 psi. The accumulator 58 sustains the pressure of the fluid which is fed to plenum 70 into plenum body 124 and plenum defining structure 116. The devices described herein are held together by means known to the prior art such as plates 82 and couplers 84. A weldment holding bracket retains stringer 30.

Figure 2A represents a cutaway section of a portion of Figure 2 showing the relative positions of the drilling head 12, the double acting intensifier 16, the accumulator 58 and the cutting fluid supply manifold 60. Intensifiers are known to the prior art and are to boost pressure of surface supplied cutting fluid. Accumulator 58 sustains uniform pressure. Accordingly, pressure intensified water at plenum 70 passes through plenum body 124 to the plenum defining structure 116 where the cutting fluid is exited through three orifice flow lines 112 at high velocities. Means are known to the prior art which may also be used to directly intensify the pressure of the cutting fluid in an open loop system. Among these are stacked serially boosting positive displacement pumps or single positive displacement pumps.

Figure 5 further discloses non-rotating housing means 120 having an interior surface defining a female structure 136 and a bearing surface 138 rotatably mating in a substantially frictionless coupling with a rotating internal retainer bearing 134. The internal retainer bearing 134 is affixed to the plenum defining structure 116 which is rotated by moments induced by the velocity vector components of orifice flow lines 112.

The housing 120 and plenum body 124 are adjustably affixed. This permits selective variation of the rotational velocity of the plenum defining structure 116 by a mere tightening or loosening of the housing 120. Tightening the housing 120 will increase the friction of bearing surfaces thereby reducing the rotational velocity of the plenum defining structure and frequency per revolution of pulsed jets exiting orifice flow lines 112. A retaining nut 122 locks the housing 120 in place. In one method an access hole 118 is utilized during assembly and disassembly of the drilling head 12 by aligning it with the inner retainer bearing 134 and inserting a pin prior to torque application to the plenum defining structure 116.

Figure 5A illustrates an alternate variation in drilling head design. The drilling head 12 comprises substantially the same principles and performs identical functions of the drilling head shown in Figure 5. The non-rotating housing 120 and plenum body 124 are adjustably affixed. This permits selection variation of the rotational velocity of the plenum defining structure 116' by a mere tightening or loosening of the housing 120. Tightening the housing 120 will increase the friction of bearing surfaces thereby reducing the rotational velocity of the plenum defining structure 116' and frequency per revolution of pulsed jets exiting through orifice flow lines 112'. A retaining nut 122 locks the housing 120 in place.

Figure 5A further discloses non-rotating plenum body 124 having an interior surface defining a female structure 136' and a housing 120 coupled to a thrust bearing 138' rotatably mating in a substantially frictionless coupling with a rotating internal retainer bearing 134'. The internal retainer bearing 134' is affixed by means of a locking taper means to the plenum defing structure 116' which is rotated by moments induced by the reaction of high velocity jets exiting through the offset, tangential orifice flow lines 112'. The locking taper means provide for rapid assembly and disassembly of the plenum defining structure 116' with the internal reatiner bearing 134'.

Figure 4A illustrates an alternate variation of the orifice flow lines 112' of the plenum defining structure 116'. The end view shows the tangential origin of the orifice flow lines 112' coming directly from the plenum having a circular cross section as defined by the plenum defining structure 116'. The orifice flow lines 112' point downward toward the workface at an approximately 25 degree acute angle from a plane normal to the axis of the plenum defining structure 116'.

Material for plenum defining structure 116 is composed of a high strength and hardness cermet that is resistant to flowing material erosion. The cermet bearing surface may be plated 128 for truing and lap fit purposes. Labyrinth seals 130 prevent leakage between the plenum body 124 and the plenum defining structure 116. Other bearing surfaces surfaces may be treated or otherwise augmented by means known to the prior art to prevent wear and leakage.

Housing 120 provides a guard and stand-off means which are disposed around the exterior surface of the plenum defining structure 116 extending in a circle below the lowest point on the plenum defining structure 116 but above a cone defined by the rotation of an extension of orifice flow lines 112 which point downward at an acute angle of about 25 degrees.

Figures 3, 3A, and 3B illustrate lateral feed motion of the drilling head 12. A preferred pattern for a single drilling head 12 is shown in Figure 3 and is referred to as a daisy pattern as projected on a planar surface. This may be altered by the control means of the reaction jets 100 or equivalent control means. Figure 3A shows one technique used to stabilize and control the drilling head 12 by the use of reaction jets 100A, B, C, D and E. Fluid flow metering of the reaction jets 100 permits the drilling head to be moved in any pattern in a pendulum-like arc. The reaction jets 100 may be oriented as shown on a stacked positive displacement pump 16 and mounted radially offset at an angle from the axis of the stringer 30 for modifying drilling head 12 motion. Figure 3B shows the daisy pattern 110 formed by pendulum-like arc motion in which the same drilling head 12 is shown in two extreme positions. The daisy pattern or alternate patterns greatly extend the lateral cutting range of the jets from the orifice flow lines 112 according to their acute angle and operating pressure. Even larger holes may be drilled simply by increasing the oscillation diameter of the daisy pattern or alternate pattern and by increasing the water pressure or by using a plurality of drilling heads 12. For medium hard rock, drilling of large holes of approximately two feet diameter using a single drilling head 12 should cut at three times the rate of prior art mechanical means.

Figures 6,7,8,and 9 show selected parts of alignment control means which activate inflators 140 or reaction jets 100 for reaction with walls 144 defining a drilled hole or with muck respectively. Inflators 140 or reaction jets 100 are disposed around the stringer 30 and are activated to the extent pursuant to instructions received from the controls 36.

Figure 6 shows in cross section air hoses 18 and lift pipes 20. The air hoses feed air downhole to inflators 140 and to the lift pipes for mucking purposes. Inflation of a particular inflator 140 causes that inflator to push against the side 144 thereby moving the stringer 30 and the drilling head 12 in the opposite direction. A precise succession of movement of the drilling head 12 may be achieved by proper inflation of selected inflators 140.as shown in Figure 8. Stability, pre-programed feed and alignment correction are simultaneously accomplished.

Figure 7 gives partially cutaway side views of inflator 140, the dynamic stabilizer 14 and columnar light sources 148 along with associated circuitry. Each light source 32 of columnar light source 148 is at a selected point substantially above the photocell arrays 126 as much as a quarter of a mile depending on drilling advance. Horizontal or non-horizontal leveling of columnar light source 148 is made with respect to the axis of stringer 30 and is accomplished by angle adjustment of two mercury switches 33. Mercury switches 33 are mounted at right angle to each other in substantially the same plane.

The photocell array system 168 shown in Figure 7 comprises photocell arrays 26 and associated power circuitry with pass through means for power and watersupply line 46 or air line 46 according to the type of control means used. The dynamic stabilizer 14 comprises the inflators 140 and associated fluid and electrical circuitry including solenoid valve 160, switch 152 and rotary switch 158.

Figures 7 and 11 may best illustrate the use of columnar light sources to align and control drilling head 12. The light sources received are converted into signals which,when amplified and applied by switching, provide metering of pressurized fluid which is air for the inflators 140 and water for the reaction jets 100 (as shown in Figure 3A). Other means known to the prior art such as electric motors or pistons (not shown) may also be used to control feed and correction of drilling head 12. Pistons would use water or air as the pressurized fluid. There may be a different number of inflators 140 or jets 100 or other means used for control. Six inflators 140 are shown in Figure 6 and five jets 100 are shown in Figure 3A. Each control device utilizes associated columnar light reference sources 148 and photocell receivers 168. Each light reference photocell array 26 of receiver 168 corresponds to an inflator 140 or reaction jet 100 control. Each photocell array comprises a plurality of cells, in this example exactly three as shown in Figure 11. As the drilling head 12 moves according to a pre-programed pattern, the top position shown represents a neutral feed with no correction for metering flow. This neutral cell receives source light 32 which is converted to an electrical signal and amplified to provide metered flow of fluid through an oppositely located solenoid valve. If overfeeding as shown in the second position, the cell provides its signal to decrease orifice size of the valve which in turn decreases inflation of inflator 140 or decreases mass for reaction jet 100,and the hole size and alignment is corrected. Underfeeding is shown in the third position. Constriction of the solenoid valve orifice reduces flow and results in a smaller hole size and alignment correction. The circuitry 150, utilized to perform this task is shown in large part in Figure 10. Parts not shown are well known to the prior art. Figure 10 shows a typical circuit comprising three amplifiers 154 coupled through adjustable resisters 152 to a rotary position switch 158 and a solenoid valve 160. Each of the three amplifiers 154 corresponds to a photocell of the array 26. The six position rotary switch 158 is utilized for flow selection among the six solenoid valves 160 and this allows for the pre-programed patterns. Other switch and circuit arrangements may be also be utilized and exist in prior art. The variable resisters 152 and diodes 156 are used to control voltage levels.

Continuous wall casing means may be utilized with the drilling means under appropriate conditions. The wall casing means comprise a plurality of radially and axially moveable segments (notshown) capable of retaining the injection material of rapidly curing chemical and shotcrete wall reinforcement composition. This permits casing to be applied concurrently with drilling and is particularly valuable when the hole is long or changes direction or varies in size. Other concepts in the present invention when applied as set forth herein also substantially reduce cycle time and down time in drilling resulting in greater net drilling time available.

CLAIMS

This invention is limited only by the following claims:

1. Hydrojet drilling means, comprising:

a base;

at least one drilling head disposed about an axis;

drilling head coupling means coupling the drilling head to the base;

stabilizing means coupled to the drilling head to stabilize the drilling head;

control means coupled to the drilling head to control the drilling head;

a source of cutting fluid coupled to the drilling head to furnish cutting fluid to the drilling head;

wherein the drilling head comprises:

a proximate fluid pressure intensification means providing a fluid input and fluid outputs;

a source of cutting fluid coupled to the pressure intensification means;

a strong plenum defining structure having interior surfaces defining a high pressure plenum having an input and at least three outputs, the input of the high pressure plenum being coupled to the output of the pressure intensification means in a substantially fluid tight coupling to receive high pressure fluid from the intensification means, the interior surface of the plenum defining structure defining generally axially symmetric plenum rotating about an axis, the output of the plenum comprising at least three orifices disposed generally symmetrically about the axis of the plenum at equal angles about the axis, the orifices comprising flow lines each in substantially the same relative orientation about the axis except for displacement about the axis at substantially equal angles from the adjacent flow lines, said orifices exiting at a downward acute angle from a plane perpendicular to the axis, the structure defining the plenum being axially symmetric and forming an exterior axially symmetric plenum structure bearing;

non-rotating housing means having an interior surface defining a female bearing structure rotatably mating in a substantially frictionless coupling with an axially symmetric rotating internal retainer bearing;

rotational velocity controlling means rotatably coupled to the rotating internal retainer affixed to the plenum defining structure to permit selective variation of rotational velocity of the plenum defining structure;

guard stand-off means disposed around the exterior surface of the portion of the plenum defining structure defining the orifices and extending in a circle below the lowest point on the plenum defining structure but above a cone defined by rotation of an extension of each orifice;

drilling head moving means capable of selectively moving the drilling head in relation to the base in a selected manner in each dimension;

mucking means;

hole casing means and means to emplace the hole casing means in drilled holes requiring hole casing means; and

power means coupled to the source of cutting fluid, the stabilizing means, the control means, the drill head coupling means, plenum defining structure, and the drilling head moving means to furnish power thereto.

2. The invention of Claim 1 wherein the stabilizing means comprises a dynamic stabilizer assembly which programs, integrates and activates a plurality of separate control means for feeding and correcting the

location of the drilling head.

3. The invention of Claim 1 wherein the control means comprise means for sequential, horizontal feed and vertical and angular adjustment thereby directly controlling the drilling head position according to correction signals, causing the drilling head to move in a general daisy pattern superimposed on a plane perpendicular to the drilling head axis which pattern is altered by the control means regulating the speed of sequencing of movement of the drilling head.

4. The invention of Claim 1 wherein the control means provides feeding and alignment adjustment by employing inflators which receive programed and metered pressurized fluid as a function of photocell signals causing the inflators to react with the walls defining a drilled hole.

5. The invention of Claim 1 further including an interior surface of the drilling means defining orifices coupled to the fluid from the source of the cutting fluid pressurized by intensifier means and controlling both cutter rotation and fluid flow velocity through the orifices of the cutter and provide cut and clear jet penetration and shear of exposed strata from a plurality of alternating directions.

6. The invention of Claim 1 further including a plurality of controlled columnar light sources coupled to the base and projected in a selected single direction, each columnar source generating a light source parallel to that of each other columnar source, and shining on a coupled one of a plurality of matching photocell arrays, one for each columnar source, coupled to means of reaction control of the drilling head a sufficient distance above the lowest point on the drilling head to remain above the waterline in a relatively close proximity to the stabilizer, the control means utilizing the columnar light sources and the light received by the plurality of matching photocell arrays from the light sources to control

orientation of the drilling head without cumulative errors and independent of the walls defining any hole drilled by the drilling head.

7. The invention of Claim 6 wherein the columnar light sources are lasers.

8. The invention of Claim 6 wherein the control means includes repositioning and relocation circuitry which permits programed sequencing and the control means to reposition the drilling head with correction during drilling pursuant to instructions from the control means.

9. The invention of Claim 8 wherein the photocell arrays that are matched and coupled to the columnar light sources generate signals as a function of where the light is received on the photocell array from the coupled columnar light source by specific in-line photocells of each array, the signals from photocells are fed to the control means which utilize the signals to control fluid reaction forces for the programed orientation and position of the drilling head.

10. The invention of Claim 1 wherein fluid is pumped from a settling pond at pressures of 250-500 psi. to the stabilizer means of control and combines with the fluid released from the control orifices to contribute to the mucking function.

11. The invention of Claim 1 wherein the drilling head is caused to move by the control means in a generally circular pendulum arc during shearing of selected material.

12. The invention of Claim 1 wherein the drilling head is caused to move by the control means in a generally elliptical pendulum arc during shearing of the selected strata.

13. The invention of Claim 1 wherein the drilling head is caused to move by the control means in a generally linear pendulum-like arc during shearing of selected material.

14. The invention of Claim 13 wherein the line of the pendulum-like arc is rotated at a selected rotational velocity.

15. The invention of Claim 1 wherein the mucking means comprises a plurality of lift pipes consisting of water pipes combined with air injection tubes which remove fluid and material from the bottom of the volume cut by the drilling head, fluid and material being pumped by at least one pump, a portion of which fluid derives from the drilling head cutting fluid which is used to enhance the mucking process.

16. The invention of Claim 15 wherein the rate of vertical and horizontal movement of the drilling head is a function of the mucking rate of the lift pipes.

17. The invention of Claim 1 wherein the bottom of the drilling head comprises a hardened take-up nut which nut retains the rotating plenum defining structure, protects the rotating plenum defining structure from impact and establishes a fixed stand-off distance for cohesive stream formation of the jets of fluid forced through the orifices of the rotating plenum defining structure of the drilling head and which nut is capable of adjusting the rotational speed of the plenum defining structure of the drilling head.

18. The invention of Claim 1 wherein labyrinth seals seal at least certain of the rotating cylindrical bearing surfaces of the plenum defining structure of the drilling head in a low leakage seal.

19. The invention of Claim 18 wherein labyrinth seals seal at least certain flat bearing surfaces of the inner retainer surface of the drilling head in a self-sealing seal.

20. The invention of Claim 19 wherein matching conical bearing surfaces of the inner retainer provide radial and axial constraint of the rotating of the plenum defining structure of the drilling head.

21. The invention of Claim 20 wherein matching conical bearing surfaces of the inner retainer absorb and translate externally applied shock loads to the bearing surfaces of the mounting base of the drilling head.

22. The invention of Claim 1 wherein the drilling means comprises a plurality of drilling heads, each drilling head including a separate rotating high pressure plenum defining structure associated with that drilling head.

23. The invention of Claim 1 wherein the drilling means comprises a plurality of rotating plenum defining structures each within its drilling head, each drilling head utilizing a common high pressure plenum to which it is coupled.

24. The invention of Claim 1 wherein the means of pressure intensification provided for the drilling means comprises a closed loop hydraulic system capable of providing and sustaining pressures of about 10,000 psi. to the cutting fluid.

25. The invention of Claim 1 wherein the means of pressure intensification used comprises at least one double acting intensifier which comprise modified end cap retaining strucures having a triangular cross-section shape to reduce the intensifier closed loop hydraulic system configuration circumferential size.

26. The invention of Claim 1 wherein the means of pressure intensification provided for the drilling means comprises open loop stacked positive displacement pumps serially boosting input cutting fluid supplied at low pressures to an output plenum pressure of about 10,000 psi.

27. The invention of Claim 26 wherein the open loop stacked series pump output pressure is augmented by pulsation reducing and damping means.

28. The invention of Claim 1 further including a continuous wall casing means comprising a plurality of radially and axially moveable

segments capable of retaining the injection material of rapidly curing chemical and shotcrete wall reinforcement material.

29. The invention of Claim 28 wherein the advancement of the wall casing means intrudes into the volume of mucking fluid just below the waterline.

30. The invention of Claim 1 wherein the control means provides feeding and alignment adjustment by employing reaction jets which receive programed and metered pressurized fluid as a function of photocell signals; the jet total impulse and fluid mass is capable of reacting with the mucking fluid and the walls defining a drilled hole.

31. The invention of Claim 1 wherein the control means provide feeding and alignment adjustment by employing pistons which receive programed and metered pressurized fluid as a function of photocell signals and the pistons exert force on the walls defining a drilled hole to align the drilling head selectively.

32. The invention of Claim 1 wherein fluid is pumped from a surface settling pond as make-up for performing the mucking function, which fluid is supplied directly proportional to the rate of mucking but limited to a level in the hole just below the photocell receiver arrays.

33. The invention of Claim 1 wherein a plurality of controlled columnar light sources comprises a leveling means adjustable for a fixed horizontal positioning of the light sources in the drilled hole.

34. The invention of Claim 1 wherein the plurality of controlled columnar light sources comprises a leveling means adjustable for a predetermined fixed non-horizontal positioning of the light sources in the drilled hole.

35. The invention of Claim 1 wherein a plurality of controlled columnar light sources comprises lowering means of the light sources to

a lower level elevation while maintaining one only of the fixed horizontal positioning of the light sources and fixed non-horizontal positioning of the light sources in the drilled hole defined by the base.

36. The invention of Claim 1 further including a rotating plenum defining structure means of a cast material of hardness and density capable of resisting material erosion by cutting fluid flow through the structure.

37. The invention of Claim 1 further including lift pipes and air injection yubes used as a collection and diversion means for pressurized fluids when such fluids are reached at producing strata and aquifers, the diversion means comprising a relief valve energized when the pumps stall because of overpressurized fluid received through the lift pipe and the relief valve diverting the overpressurized fluid to storage.

38. Continuous wall casing means comprising a plurality of radially and axially moveable segments capable of retaining the injection material of rapidly curing chemical and shotcrete wall reinforcement material.

39. The method of drilling a hole about a selected line utilizing cutting fluid, comprising:

increasing the pressure of the fluid to thousands of psi. by means of a pressure intensifier;

causing the fluid to flow through at least three narrow orifices defined by the interior surfaces of a hydrojet drilling head, the three orifices being disposed at equal angles about an axis of a plenum defining strucure, each orifice having a diameter of less than 0.050 inches and each orifice exiting the drilling head at an angle approximately 25 degrees below a plane perpendicular to the direction of drilling, the last approximately half of the length of each orifice prior to exiting from the plenum defining structure being disposed about an orifice axis;

continually lowering the drilling head at a selected drilling rate to cut back adjacent surfaces defining the hole in the strata;

mucking the cuttings out of the hole at approximately the same rate they are cut by the drilling head;

rotating the plenum defining structure so that the fluid emitted from the orifices is continually emitted at a different angle;

swinging the drilling head back and forth so that the orientation of the drilling head with respect to the walls of the hole continually changes so that the interior surface defining the hole is cut by streams of high pressure fluid coming from a variety of directions and a variety of angles thereby chipping relatively large pieces from the strata by shearing.

40. The invention of Claim 1 wherein a plenum defining structure has at least three orifice flow lines equally spaced circumferentially and tangentially originating from a plenum of circular cross section; the orifice flow lines pointing downward at a acute angle from a plane perpendicular to the axis of the plenum defining structure.

41. The invention of Claim 1 wherein a plenum defining structure is fixedly coupled to an internal retainer bearing by means of a locking taper.

42. The invention of Claim 1 wherein the motion from control means for at least one drilling head is lateral during rotational and linear feeding.

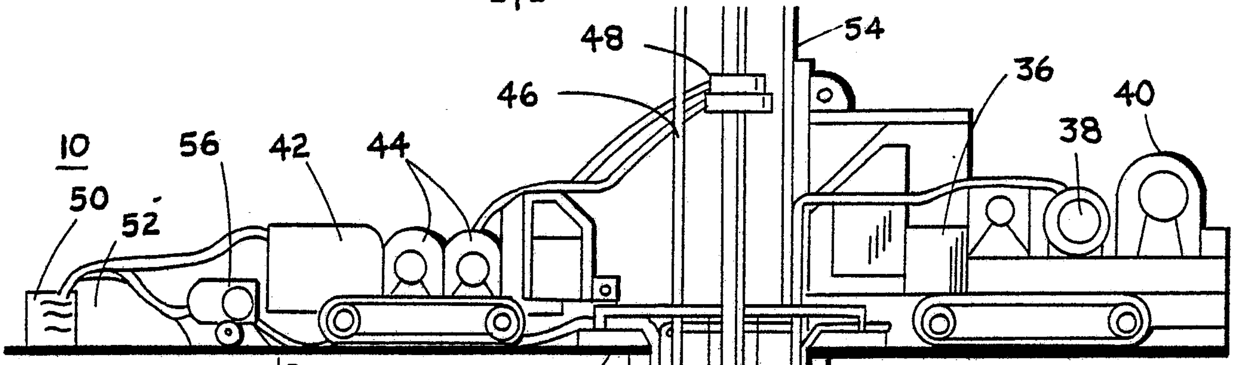
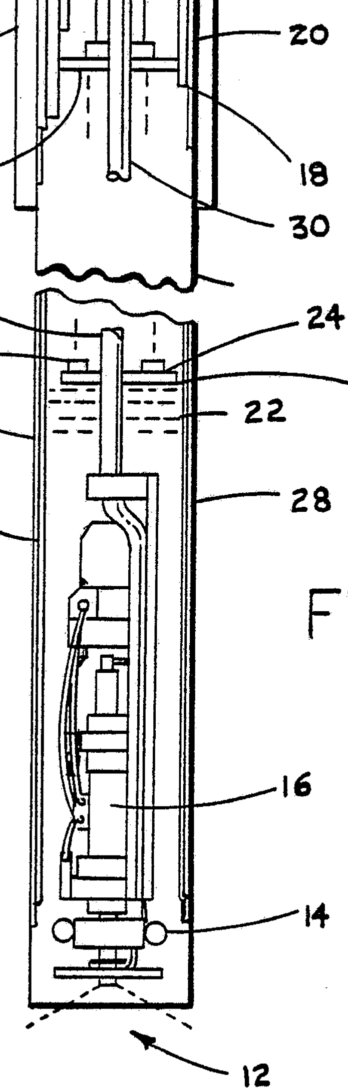



FIG. 1

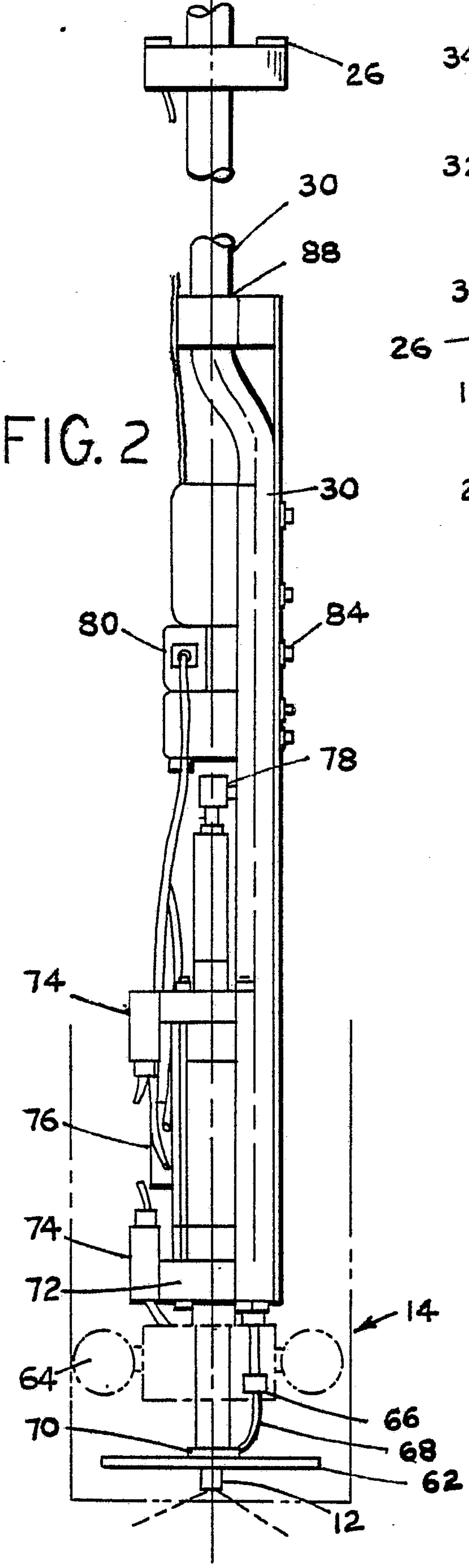
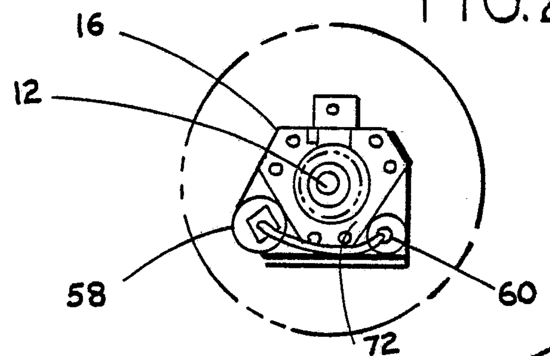


FIG. 2

FIG. 2A



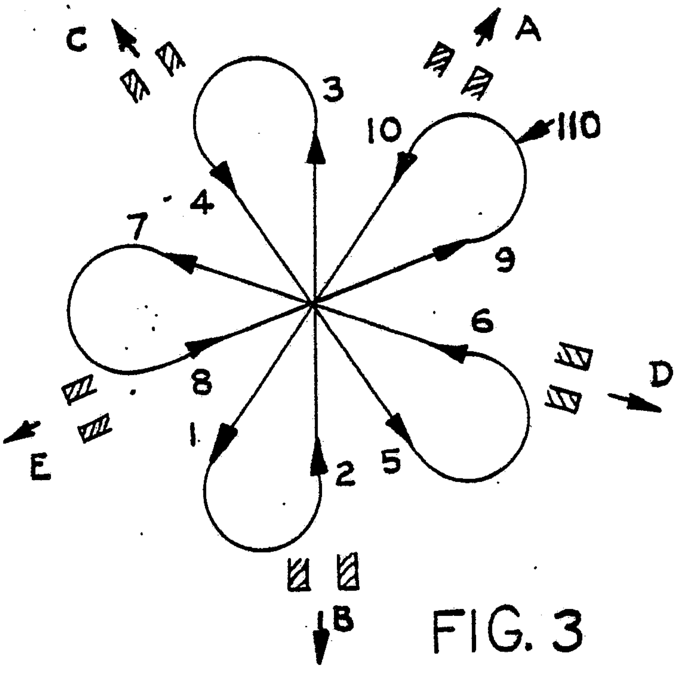


FIG. 3

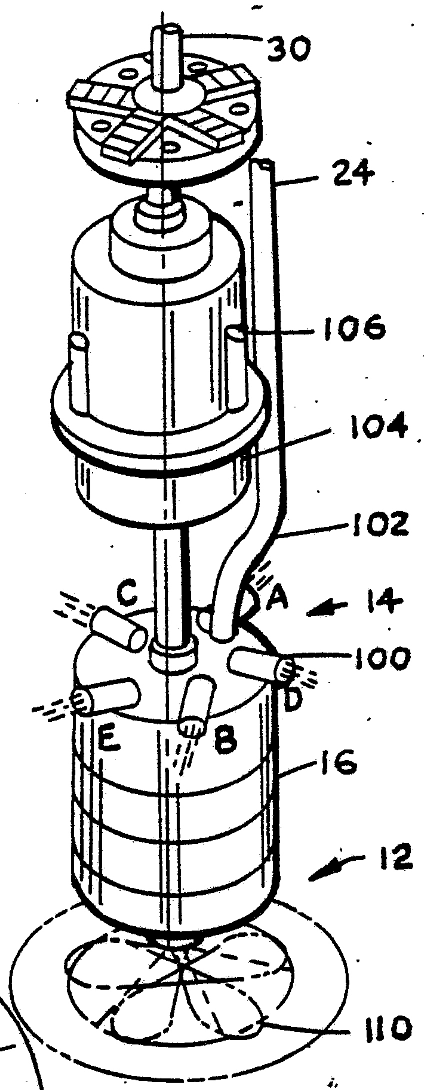
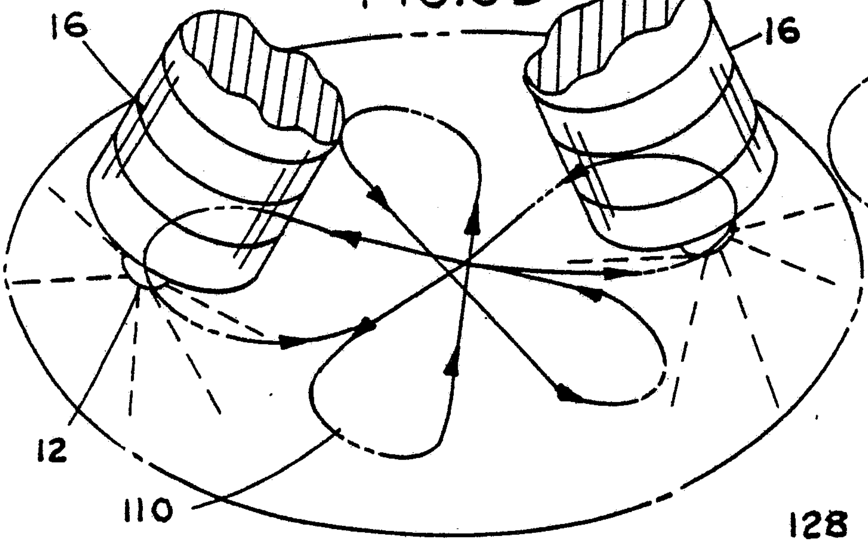


FIG. 3A

FIG. 3B



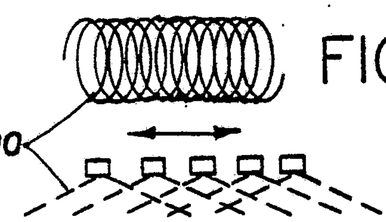
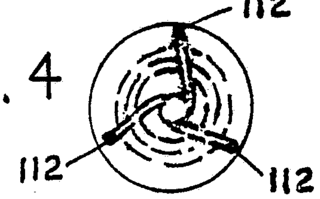


FIG. 3C

FIG. 4



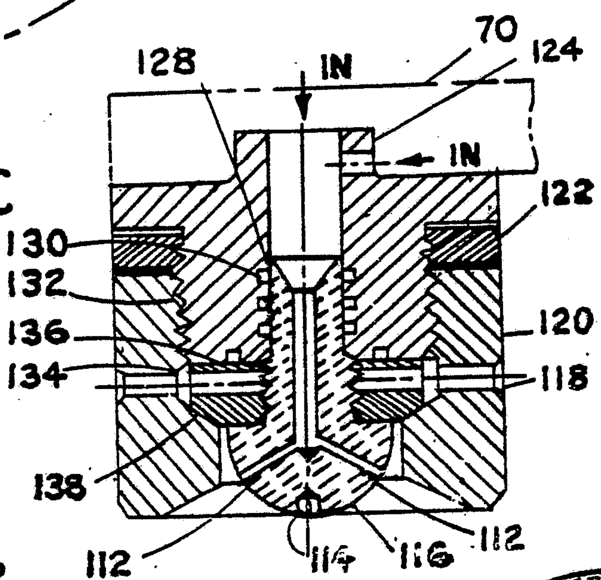


FIG. 5

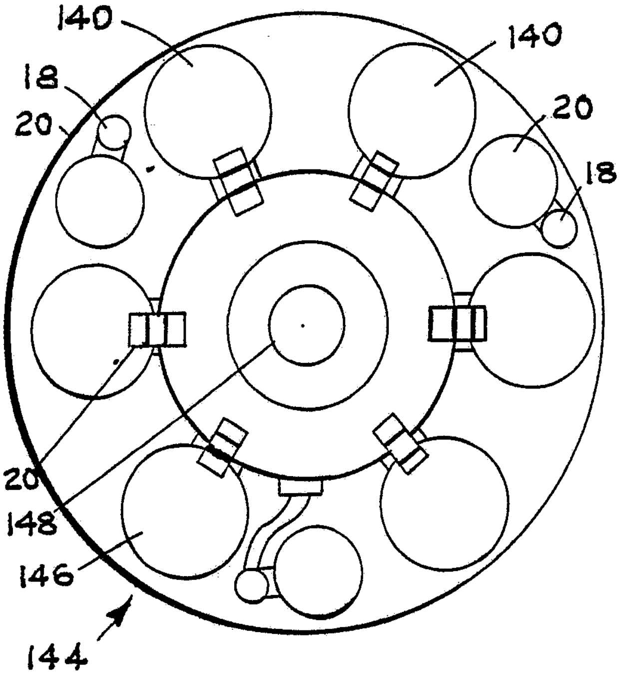


FIG. 6

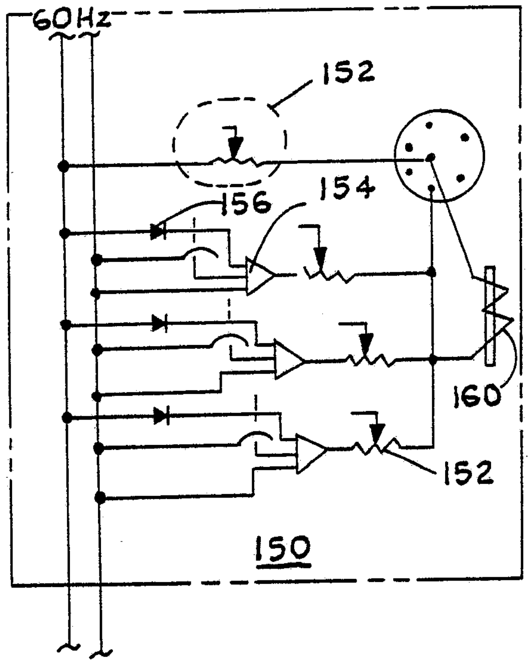


FIG. 10

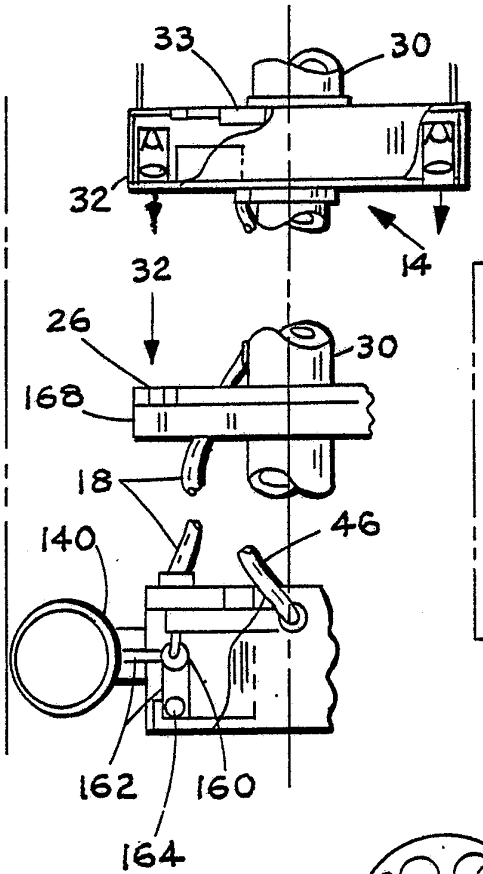


FIG. 7

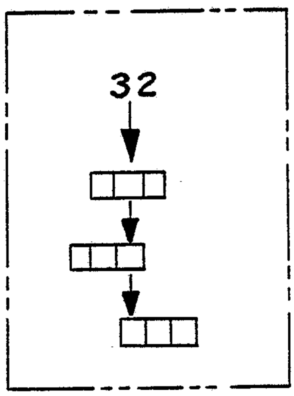


FIG. 11

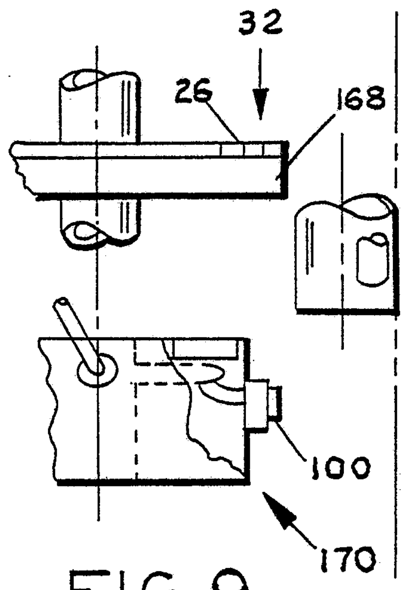


FIG. 9

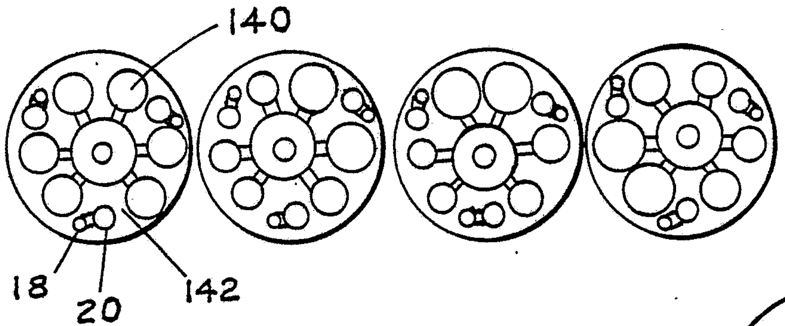


FIG. 8

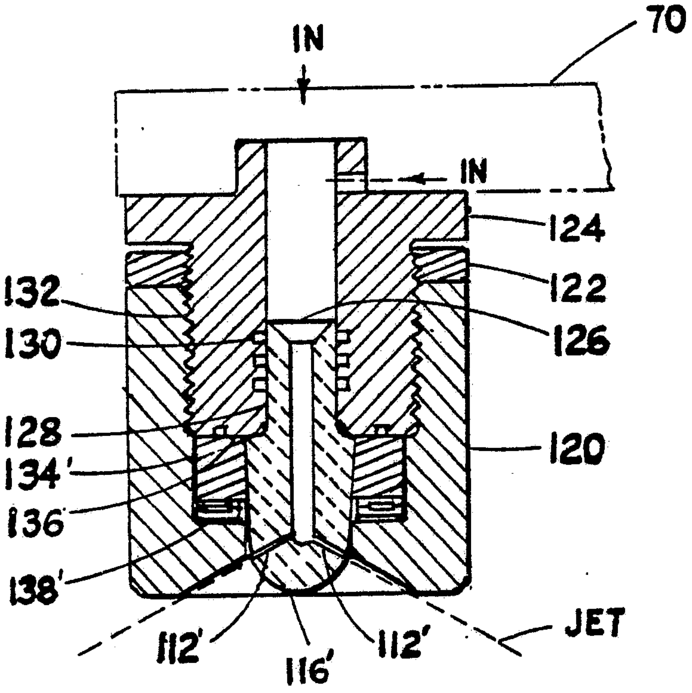

70
IN
IN
124
122
132
126
130
128
120
134'
136
138'
JET
112'
112'
116'

FIG. 5A

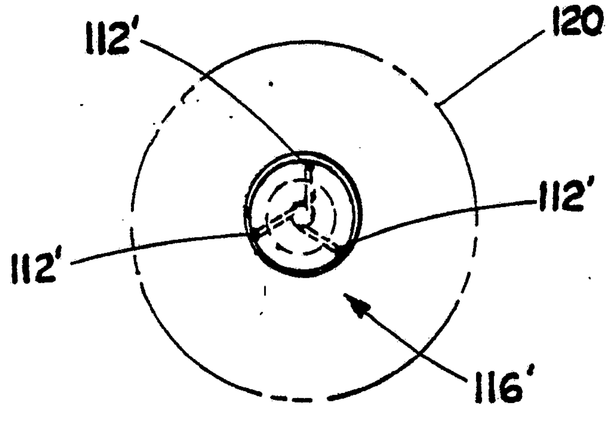

112'
120
112'
112'
116'

FIG.4A

INTERNATIONAL SEARCH REPORT

International Application No PCT/US83/01450

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [3]

According to International Patent Classification (IPC) or to both National Classification and IPC

INT. CL.[3] E21B 44/00, 7/18, 10/60
U. S. CL. 175/25

II. FIELDS SEARCHED

Minimum Documentation Searched [4]

Classification System	Classification Symbols
U. S.	175/25,65,67,422 166/222,223,242; 299/17

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [5]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [14]

Category *	Citation of Document, [16] with indication, where appropriate, of the relevant passages [17]	Relevant to Claim No. [18]
A	US, A, 3,547,191, (MALOTT) 15 December 1970	
A	US, A, 3,844,362, (ELBERT ET AL.) 29 October 1974	

* Special categories of cited documents: [15]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search [2]	Date of Mailing of this International Search Report [2]
19 December 1983	22 DEC 1983
International Searching Authority [1]	**Signature of Authorized Officer [20]**
ISA/US	Bunlhu

Form PCT/ISA/210 (second sheet) (October 1981)

FURTHER INFORMATION CONTINUED FROM THE SECOND SHEET

V. ☐ OBSERVATIONS WHERE CERTAIN CLAIMS WERE FOUND UNSEARCHABLE [10]

This international search report has not been established in respect of certain claims under Article 17(2) (a) for the following reasons:

1. ☐ Claim numbers ...., because they relate to subject matter [12] not required to be searched by this Authority, namely:

2. ☐ Claim numbers ...., because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out [13], specifically:

VI. ☒ OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING [11]

This International Searching Authority found multiple inventions in this international application as follows:

Invention I: Claims 1-37 and 40-42

Invention II: Claim 38

Invention III: Claim 39

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.

2. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the international application for which fees were paid, specifically claims:

3. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim numbers:

4. ☐ As all searchable claims could be searched without effort justifying an additional fee, the International Searching Authority did not invite payment of any additional fee.

Remark on Protest

☐ The additional search fees were accompanied by applicant's protest.

☐ No protest accompanied the payment of additional search fees.