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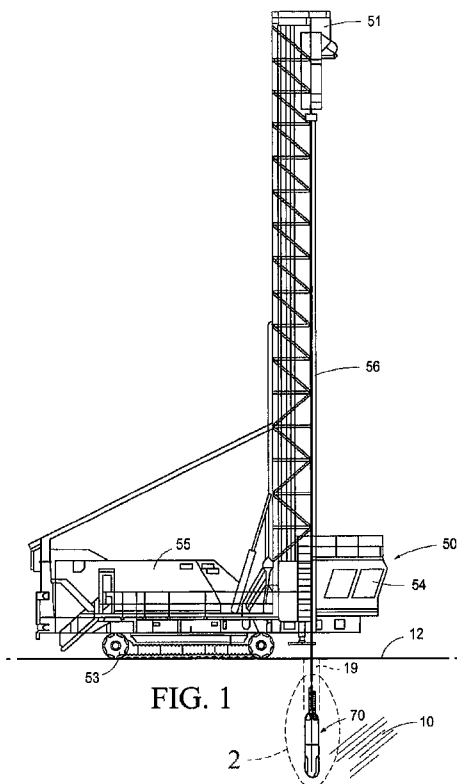
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(54) Title: METHOD OF MINING USING A LASER



(57) Abstract: A method for mining using a laser to cause spalling includes the steps of generating and delivering a laser beam to a work surface of a geological strata having a sought after mineral to be removed from the stratum; moving the laser beam about three perpendicular axes so that a focal point of the laser beam moves across the working surface and rapidly increases the surface temperature of the working surface; providing a source of a cooling media, and delivering the cooling media to the working surface so as to rapidly cool the working surface subsequent to the rapid surface temperature increase generated by the laser beam so as to effect a fracturing of the working surface and to generate a plurality of chips from the working surface; and removing the chips spalled from the working surface.

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METHOD OF MINING USING A LASER

DESCRIPTION

5 TECHNICAL FIELD

The present invention relates to a method for mining. More specifically, the present invention relates to an improved method of using a high power laser for spalling a strata to facilitate extraction of sought after minerals from the spalled stratum chips.

10

BACKGROUND ART

Conventional rotary drilling methods for drilling holes in rock for mining and for gas and oil wells, use a rotary/vibratory drill bit interconnected to a long length of drill pipe, also called the drill string
15 which is rotated by mechanical apparatus.

The drill bit may be constructed from a variety of materials, such as, but not limited to tungsten, carbide, steel, diamond, and the like. Drill bits are typically specialized for various rock/strata formations, hereinafter referred to as "stratum". Drill bits "wear out" and "break
20 down" during drilling processes. Replacement of a drill bit requires removal of the drill string and drill bit from the drilled hole. To keep a

drilled hole from collapsing inwardly upon itself, a casing may need to be installed and perhaps even cemented into the drilled hole.

Chips and rock fragments broken from the stratum by the friction and rotation of the drill bit within the drilled hole are removed from the drilled hole by pumping "drilling mud" at high pressure through an axial channel defined in the drill stem from the surface downwardly to the bottom of the hole being drilled. The drilling mud exits the drill stem through orifices defined in the drill bit. The high pressure exerted on the drilling mud passing through the drill stem causes the drilling mud, and chips and rock fragments, to be pushed, moved and floated upwardly along an exterior surface of the drill stem until the drilling mud and carried rocks/chips exit the drill hole at the point where the drill hole was initiated, typically at the surface. The use of drilling mud to remove rocks and chips from the drilled hole and also to cool the drill bit to prevent overheating adds a significant cost and complexity to drilling operations.

Reductions in drilling costs can be achieved by reducing requirements for drilling mud, drill string removal, drill bit replacement and setting of casings.

In underground mining operations, normally there are crosscuts driven from entry portals. From such crosscuts, drifts are mined

following veins of ore. Drifts may be anywhere from two feet to over ten feet in width to any height the operator chooses, based on safe mining practices and height needed for mining equipment. The face of the drift is ordinarily prepared for blasting by drilling holes in a
5 predetermined pattern and to a predetermined depth. The drilled holes are then packed with explosive media. The explosive charges are detonated to fracture the strata for removal of the sought after mineral and yet maintain the integrity of the strata and the drift. In many mines, the regular progression of daily drilling and blasting may
10 exacerbate or induce "rock bursts". By eliminating drilling and blasting, mining is safer.

Lasers have been demonstrated to be effective in drilling and the rate of penetration of strata by lasers can be faster than current rates of penetration using mechanical drill bits. This saves drilling time and
15 costs.

High power lasers can remove rock by vaporization, melting, and spallation which reduces the need for drilling mud to remove chips and fragments. Spallation is a rock removal process that utilizes a combination of laser-induced thermal stress and laser-induced
20 superheated steam explosions just below the surface of the laser/rock interaction to fracture the rock into small fragments that can then be

easily removed from the rock formation. High intensity laser energy, applied to a stratum causes the stratum surface temperature to increase instantaneously. This results in thermal stresses in the stratum subsurface. The laser energy also instantaneously vaporizes
5 any moisture or liquid in the stratum subsurface. The explosion of the vaporized liquid creates significant mechanical stresses causing fractures. These laser-induced thermal and mechanical stresses spall the stratum which allows removal of the spalled chips with a vacuum.

Mine operators have continued their search for methods of
10 removing valuable sought-after minerals between the drifts, particularly in narrow vein situations. The mining practices employed heretofore to extract such sought-after minerals are effective, but require considerable manpower and expense for the tonnage involved. At present, the difficulties and costs of mining to even greater depths
15 following veins down dips has become less profitable and working conditions for the miners more difficult. The instant invention uses a single laser drill head, or plural cooperating laser drill heads in a mining array to operate cooperatively. The laser drill heads operatively communicate with a high power optical laser in the 1.6 to 2 kilowatt
20 power range to spall/ break roughly pea sized chips of material from a work surface.

Some or all of the problems, difficulties and drawbacks identified above and other problems, difficulties, and drawbacks may be helped or solved by the inventions shown and described herein. My invention may also be used to address other problems, difficulties, and drawbacks not set out above or which are only understood or appreciated at a later time. The future may also bring to light currently unknown or unrecognized benefits which may be appreciated, or more fully appreciated, in the future associated with the novel inventions shown and described herein.

10

SUMMARY

A method for mining using a high-power laser to instantaneously heat and sequentially rapidly cool stratum to cause spalling of the stratum which contains a sought after mineral.

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One aspect of the instant method for mining using a laser to cause spalling includes the steps of generating and delivering a laser beam to a work surface of a geological strata having a sought after mineral to be removed from the stratum; moving the laser beam about three perpendicular axes so that a focal point of the laser beam moves across the working surface and rapidly increases the surface temperature of the working surface; providing a source of a cooling

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media, and delivering the cooling media to the working surface so as to rapidly cool the working surface subsequent to the rapid surface temperature increase generated by the laser beam so as to effect a fracturing of the working surface and to generate a plurality of chips
5 from the working surface; and removing the chips spalled from the working surface.

A second aspect of the instant method for mining using a laser to cause spalling includes the steps of providing a geological strata having a sought after mineral to be removed; delivering a laser beam
10 to a working surface of the geological strata the laser beam having a power output which is sufficient to spall small chips of the working surface of the geological strata; moving the laser beam along a predetermined path of travel across the working surface, and wherein the delivery of the laser beam to the working surface increases the
15 surface temperature of the working surface; providing a source of a cooling media and delivering the cooling media to the working surface so as to cool the working surface temperature below a temperature which encourages spalling; removing at least in part, a portion of the spalled chips generated from the working surface; and delivering the
20 removed spalled chips to a remote area for processing to remove the sought after mineral from the removed spalled chips.

A third aspect of the instant method for mining using a laser to cause spalling includes the steps of providing a geological stratum having a sought after mineral; providing a working surface of the stratum and upon which the method of mining may be operated; 5 providing sources of compressed air, electrical energy and electromagnetic radiation; generating a laser beam with the sources of electricity and electromagnetic radiation, the generated laser beam having a power sufficient to cause a spalling of the stratum and sought after mineral forming the work surface; providing a flexible cable 10 having a first end portion, and a second end portion, and wherein the first end portion of the flexible cable operatively communicates with the source of electromagnetic radiation, the source of compressed air, and the source of electrical energy; delivering the generated laser beam to the first end portion of the flexible cable for transmission 15 therealong; providing a laser drill head having a first end portion and a second end portion, and wherein the second end portion of the laser drill head operatively communicates with the second end of the flexible cable and receives the electromagnetic radiation from the source of electromagnetic radiation, the laser beam which the flexible cable 20 receives and passes therealong, the compressed air from the source of compressed air, and the electrical energy from the source of electrical

energy; providing a rotating scanning head at the first end portion of the laser drill head which operatively communicates with the source of electromagnetic radiation, and wherein the rotating scanning head has a protective and transparent window at a first end portion, and plural, 5 internal, reflective optical elements which are located in predetermined spaced relation relative to the protective transparent window and which are further contained within a body of the laser drill head, and wherein the reflective optical elements are individually controllably movable to transmit the laser beam through the protective transparent window and 10 onto a spall area of the work surface, and which is proximate to the rotating scanning head, and wherein the laser beam is moved in a given pattern having a predetermined scanning time, and a predetermined dwell time, so as to cause spalling of the stratum which generates a multiplicity of spalled chips; delivering the compressed air 15 to the rotating scanning head so as to both cool the internal, reflective optical elements, and the spall area subsequent to irradiation by the laser beam so as to thermally control the stratum and sought after mineral, and which further promotes the cooling of the spall area while inhibiting the melting and vaporization of the stratum and the sought 20 after mineral; removing the spalled chips from the spall area by the use of the source of compressed air; providing a chip removal system

having an evacuation port which is proximate to the rotating scanning head for evacuating the spalled chips from the spall area, and for propelling the spalled chips toward the second end of the laser drill head, and to a remote location for collection and processing; providing
5 a drive unit to move the laser drill head along a predetermined path of travel relative to the work surface, and to further maintain a predetermined desirable distance between the rotating scanning head and the working surface so as to facilitate effective spalling and the generation of the spalled chips; and providing a controller operatively
10 communicating with, and controllably coupled to the laser drill head, the drive unit, the source of electromagnetic radiation, the source of compressed air, the source of electrical energy, and the removal system, and wherein the controller is located remotely relative to the laser drill head, and further controls the operation of the laser drill
15 head, the delivery of the compressed air, and the removal of the spalled chips by way of the chip removal system.

These and other aspects of my invention will appear from the following specification and accompanying drawings which form a part hereof and which will be discussed in greater detail hereinafter.

20

BRIEF DESCRIPTION OF THE DRAWINGS

Preferred embodiments of the invention are described below with reference to the following accompanying drawings.

Figure 1 is an orthographic side view of a drill rig carrying a vertically oriented drill string with a laser drill head within a borehole at
5 a bottom terminal end portion of the drill string.

Figure 2 is an enlarged orthographic side view of the laser drill head of Figure 1.

Figure 3 is an isometric top, front and side view of a mining array carrying four spacedly adjacent laser drill heads, and x-ray
10 fluorescence emitter/receiver, illumination devices, video cameras and a chip receiver.

Figure 4 is an orthographic partial cutaway side view of a laser drill head with a transverse drive mechanism attached to a vertical work surface.

15 Figure 5 is an orthographic, partial cutaway, side view of an equipment transport vehicle carrying an occupant compartment, the controller, the user interface, the source of electromagnetic radiation, the source of compressed air and the source of electrical energy as well as a hoist mechanism for the flexible cable communicating with the
20 mining array.

Figure 6 is an isometric front, top and side view of one embodiment of a laser drill head for use on a mining array.

Figure 7 is an orthographic partial cutaway side view of a laser drill head configured for borehole mining showing the internal
5 components thereof.

Figure 8 is an enlarged orthographic partial cutaway side view of a laser drill head configured for borehole mining showing the internal components thereof.

Figure 9 is an orthographic schematic diagram of an equipment
10 transport vehicle lowering a mining array into a mining winze and the mining array commencing laser mining therein.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

My method for mining using a laser to cause spalling of a
15 geological stratum 10 containing sought after mineral 11 which may be in the form of a vein 11a, or in the form of an ore 11b generally comprises a source of compressed air 20, a source of electrical energy 30, a source of electromagnetic radiation 40, an equipment transport vehicle 50, a flexible cable 60, a laser drill head 70, and a controller
20 250 with a user interface 251.

A working surface 12 of the geological stratum 10 and sought after mineral 11 is identified, and may be without limitation, a vertical surface, a horizontal surface, or an angulated surface and further maybe located, without limitation, within a mining shaft 16, a mining drift 17 or a mining winze 18. As noted previously, the sought after mineral 11 which may include, but not be limited to, gold, silver, platinum and the like may be in the form of a vein 11a within the stratum 10 or may be in the form of an ore 11b.

The equipment transport vehicle 50 may have a variety of configurations, but in the disclosed embodiment has moving means 53, such as, but not limited to, wheels and/or tracks to facilitate movement, carries an occupant compartment 54, and may also carry the source of compressed air 20, the source of electrical energy 30, the source of electromagnetic radiation 40 and the controller 250.

The source of compressed air 20 is an air compressor (Figure 5) and the source of electrical energy 30 is a generator. (Figure 5). The source of electromagnetic radiation 40 is contemplated to be a fiber laser 40a such as a YLS-2000 fiber laser which is commercially available and manufactured by companies such as, but not limited to, IPC Photonics, Inc. of Oxford, MA, USA. The fiber laser 40a will operate in a power range of approximately 1.2 to about 2.4 kW, and preferably

between about 1.6 kW and 2.0 kW. Transport of the source of compressed air 20, the source of electrical energy 30, the source of electromagnetic radiation 40, the controller 250 and the occupant compartment 54 by the equipment transport vehicle 50 allows my
5 method of mining to be moved from location to location providing portability and maneuverability and ease of setup. Further, depending upon the type of mining to be performed, the equipment transport vehicle 50 may also include a crane mechanism 51 (Figure 5) having a cable spool 52 rotatable about an axis (not shown) so as to efficiently
10 and effectively store a length of the flexible cable 60 which allows for raising and lowering of the mining array 300. Further still, the equipment transport vehicle 50 may also be a drill rig 55 (Figure 1) which may affix the laser drill head 70 to a lower end portion of a drill string 56. Attaching the laser drill head 70 to a drill string 56 is useful
15 when a borehole 19 is being drilled.

The equipment transport vehicle 50, the source of compressed air 20, the source of electrical energy 30, the source of electromagnetic radiation 40 and the controller 250 may all be operated by an operator (not shown) within the occupant compartment 54 of the equipment
20 transport vehicle 50 which provides the operator/occupant with protection and allows the operator to be located remotely from the

actual mining operation and the work surface 12 which promotes worker safety. Remote location of the operator enhances safety because personnel need not be subjected to/exposed to noise, smoke, vapors, fumes, gases and rock bursts and the like that may be
5 generated during mining operations.

The flexible cable 60 may be carried on the cable spool 52 and has a first end portion 61 and a second end portion 62. The flexible cable 60 defines multiple individual conduits 63 extending from the first end portion 61 to the second end portion 62 so that pressurized
10 air from the source of pressurized air 20, electricity from the source of electrical energy 30, a laser beam 83 from the source of electromagnetic radiation 40 and other resources may be transmitted therealong from the first end portion 61 to the second end portion 62. The multiple individual conduits 63 may be hollow, such as for passage
15 of solid or gaseous materials therethrough, or the individual conduits 63 may be solid (optical fiber, or wire) such as for passage of light or electricity therethrough. It is further contemplated the flexible cable 60 also includes shielding (not shown) to protect the individual conduits 63, and the contents thereof flowing or otherwise passing
20 therethrough, from contents of adjacent conduits 63 so that, for example, the electricity passing through the flexible cable 60 does not

negatively affect the laser beam 83 that is simultaneously passing through another conduit 63 of the flexible cable 60.

A high power fiber coupler 64 is carried at the first end portion 61 and at the second end portion 62 of the individual conduit 63 transmitting the laser beam 83 to provide operable interconnections with the source of electromagnetic radiation 41, at the first end portion 61, and an operable interconnection with the laser drill head 70, at the second end portion 62. High power fiber couplers 64 and collimators 77 are known in the industry and are commercially available from manufacturers such as, but not limited to, IPG Photonics, Inc. The high power fiber coupler 64 ensures that electromagnetic radiation, namely the laser beam 83, is not negatively affected by passing through a physical interconnection between operatively cooperating elements of the system.

The laser drill head 70 is operatively interconnected to the second end portion 62 of the flexible cable 60. The high power fiber coupler 64 interconnects the conduit 63 transmitting the laser beam 83 with a collimator 77 carried within the laser drill head 70. The laser drill head 70 may be positioned remotely from the equipment transport vehicle 50. The laser drill head 70 receives the generated laser beam

83, electricity (not shown) and pressurized air (not shown) through the flexible cable 60.

The laser drill head 70 has a body 71 which is generally somewhat cylindrical in configuration. The laser drill head body 71 has a rotating scanning head 76 at a first end portion 73 and an opposing second end portion 74. The flexible cable 60 and high power fiber coupler 64 interconnect with the second end portion 74. The rotating scanning head 76 rotates axially relative to the second end portion 74 at a circumferentially extending joint 79. The body 71 defines an interior chamber 72 and carries within the interior chamber 72, plural spacedly arrayed and individually controllably movable reflective optical elements 85, a laser beam collimator 77, plural azimuth drives 105, a cooling channel 120, an evacuation channel 135 as well as other various operating components including known electronics, pneumatic plumbing and connections therefore.

The rotating scanning head 76 is rotated by a rotating means such as a servo controlled direct drive DC torque motor (not shown) which, when energized, causes the rotating scanning head 76 to rotate axially relative to the second end portion 74. Rotation of rotating scanning head 76 allows spall area 15 to be a semi-hemispherical shape. A protective transparent window 80 is carried at a first end

portion of the rotating scanning head 76 opposite the flexible cable 60 and forms a transparent barrier through which the laser beam 83 may pass from the plural internal reflective optical elements 85 to the spall area 15 of the work surface 12. As shown in Figures 7 and 8, the plural
5 reflective optical elements 85 include a folding mirror 90, an oscillating mirror 95 and a scanning mirror 100, all of which are mounted at predetermined locations and are movable on servo controlled azimuth drives 105 each of which allow $\pm 180^\circ$ of travel. Each of the servo controlled azimuth drives 105 operatively communicates with and
10 which are controlled by the controller 250 and user interface 251. Each of the mirrors 90, 95, 100 is comprised of a highly reflective coating (not shown) on a thermally stable substrate (not shown). The highly reflective coatings (not shown) are commercially available by manufacturers such as, but not limited to, ELCAN Optical Technologies,
15 Inc. of Richardson, TX, USA, but the formulation of the highly reflective coating is a proprietary trade secret of the manufacturer and not available for disclosure herein.

The physical positioning of the plural internal reflective optical elements 85 within the interior chamber 72 is such that the folding
20 mirror 90, which has the highly reflective surface, receives the collimated laser beam 83 from the laser collimator 77. The laser beam

83 strikes the highly reflective surface of the folding mirror 90 and is reflected therefrom to the oscillating mirror 95 which similarly has a highly reflective surface thereon. The oscillating mirror 95 dithers at an adjustable rate to deviate the laser beam 83 by one beam diameter.

5 The laser beam 83 received by the oscillating mirror 95 is thereafter reflected, from the reflective surface, to the scanning mirror 100 which similarly has a highly reflective surface thereon. The scanning mirror 100 is movable about an axis (not shown) so as to provide an elevation arc 101 of $+22.5^\circ$ to -22.5° . The elevation arc 101 of the scanning

10 mirror 100 is controlled by an azimuth drive 105 and the controller 250. Movement of the scanning mirror 100 causes laser beam 83 to move back and forth about the elevation arc 101. The scanning mirror 100 is positioned spacedly adjacent inward of the protective transparent window 80 and within the interior chamber 72 of the

15 rotating scanning head 76 so that the laser beam 83 reflecting off of the scanning mirror 100 is transmitted/passed through the protective transparent window 80 and onto the work surface 12 where the laser beam 83 irradiates the stratum 10 within the spall area 15. Rotation of the rotating scanning head 76, which includes the protective

20 transparent window 80, in combination with the back and forth scanning of the laser beam 83 along the elevation arc 101 caused by

the movement of the scanning mirror 100 causes the laser beam 83 to irradiate a generally circular area which is the spall area 15. Within the spall area 15, the laser beam 83 irradiates the stratum 10 and causes instantaneous heating of the stratum 10 which results in thermal fractures, instant vaporization of moisture and ultimate spalling which causes the work surface 12 spall area 15 to fracture and break forming small fragments, pieces and chips 150 approximately the size of a "pea". Rapid movement of the laser beam 83 across and about the spall area 15 with a predetermined scan time, and predetermined dwell time generates instantaneous heating and fracturing of the stratum 10 while minimizing vaporization and melting of the stratum 10 and/or melting/vaporization of the spalled chips 150 which would lead to destruction and loss of the sought after material 10.

The evacuation channel 135 and the cooling channel 120 are carried within the medial chamber 72 of the laser drill head 70. The cooling channel 120 receives pressurized air from the source of compressed air 20 which is carried to the laser drill head 70 through one of the conduits 63 defined in the flexible cable 60. The cooling channel 120 defines plural cooling orifices 125 within the medial chamber 72 so that pressurized air may be directed about and upon each of the plural internal reflective optical elements 85 as well as the

collimator 77 to provide cooling thereto and thermal control thereof. An air curtain orifice 146 is defined in the rotating scanning head 76 proximate to the protective transparent window 80. The air curtain orifice 146 is configured into a nozzle that causes pressurized air emitted from the air curtain orifice 146 to form an air curtain (not shown) over and about an exterior surface of the protective transparent window 80. The air curtain (not shown) protects the transparent window 80 from dust, debris, spalled chips 150 and the like generated from the spalling. The air curtain (not shown) simultaneously “pushes” the spalled debris and chips 150 away from the work surface 12 and also cools the exterior surface of the transparent window 80 and the work surface 12. The air curtain orifice 146 pneumatically communicates with the cooling channel 120 and likewise with the source of compressed air 20 which is located remotely from the laser drill head 70.

An evacuation port 130 is also defined in the rotating scanning head 76 proximate to the protective transparent window 80 and preferably spaced apart from the air curtain orifice 146. The evacuation port 130 communicates with the evacuation channel 135 which is carried within and extends through the interior chamber 72 of the laser drill head 70 from the first end portion 73 to the second end portion

74 and provides a means by which chips 150 spalled from the work surface 12 are removed from the spall area 15 and moved toward the second end portion 74 of the laser drill head 70 and thereafter transported to a distal location by means of a chip removal system 200
5 for further processing. The evacuation port 130 functions as a vacuum head to remove the spalled chips 150 from the work surface 12.

Depending upon the configuration of the laser drill head 70 being used, a drive unit 220 be carried on an external surface of the laser drill head 70. (See Figure 4). The drive unit 220, which
10 communicates with the controller 250 and user interface 251, allows the laser drill head 70 to be moved axially forwardly and rearwardly to maintain a desirable predetermined distance 14 between the rotating scanning head 76 and the spall area 15 on the work surface 12. Maintaining the predetermined desirable distance 14 between the
15 rotating scanning head 76 and the spall area 15 facilitates effective performance of the laser drill by maintaining an infinite focal length laser beam 83 which projects the laser beam energy on the spall area 15 surface. In the presently disclosed embodiment, the predetermined desirable distance 14 is between approximately 75mm and 250mm,
20 and more preferably between approximately 100mm and 200mm. In the current embodiment, the drive unit 220 is a transverse drive unit

221 having plural pneumatic actuators 224 that expand and contract axially, and a face attachment 225 affixed to the work surface 12. In other contemplated embodiments, the drive unit 220 may comprise a stationary gear rack 222 and a rotating gear 223 that operatively
5 communicate with one another. The face attachment 225 is releasably positionally secured to the work surface 12 spacedly adjacent the spall area 15. The actuators 224 communicate between the face attachment 225 and the laser drill head body 71. The actuators 224 axially expand and axially contract responsive to pneumatic pressure supplied thereto
10 causing the laser drill head 70 to move axially forwardly and rearwardly as controlled by the controller 250.

In the second contemplated embodiment, the rotatable gear 223 operatively engages with the gear rack 222 carried by the laser drill head body 71. Rotation of the gear 223 engaged with the gear rack
15 222 causes the laser drill head 70 to move relative to the work surface 12 so that the predetermined desirable working distance 14 may be maintained. The drive unit 220 operatively communicates with the controller 250 by means of the flexible cable 60 so that an operator, located distally from the laser drill head 70, may control the movement
20 of the laser drill head 70 by operation of the drive unit 220.

As chips 150 are spalled from the work surface 12 spall area 15 and the borehole 19 increases in depth, the laser drill head 70 is advanced forwardly, by axial expansion of the actuators 224, or rotation of the gear 223, to continuously maintain the predetermined
5 desirable distance 14 between the rotating scanning head 76 and the spall area 15.

The prior disclosed configuration of my laser drill head 70 is useful when a borehole 19 is being drilled, such as for later packing with explosives for blasting, or when the laser drill head 70 is attached
10 to a terminal end portion of a drill stem 56 operated by a drill rig 55. (Figure 1).

In a second contemplated embodiment, as shown in Figure 3, plural laser drill heads 70 may be carried upon a mining array 300 to cause spallation over and aurally larger spall area 15 which may be
15 useful when the sought after mineral 11 is contained within an ore 11b type stratum 10. (Figure 9). The mining array 300 (Figure 3) has a frame 310 that is generally rectilinear having two horizontally spaced upper beams 311 and two horizontally spaced lower beams 312, the upper beams 311 and the lower beams 312 each having opposing end
20 portions. A horizontal transverse beam 313 extends between the spacedly adjacent end portions of the two upper beams 311, and also

between the spacedly adjacent end portions of the two lower beams 212 to maintain the upper beams 311 and the lower beams 312 in horizontal parallel spaced adjacency. Vertical spacing beams 314 structural interconnect the adjacent end portions of the upper beams 5 311 and the lower beams 312 to form the generally rectilinear frame 310. A cable mount arch 340 extends parallel to the two spaced apart upper beams 311 and interconnects at its end portions with the upper horizontal transverse beams 313 at generally medial positions thereon. The arch 340 supports a cable mount 341 for releasable engagement 10 with the flexible cable 60 carried by the equipment transport vehicle 50 and its crane mechanism 51. A chip receiver 320 is carried vertically below the two spaced apart lower beams 312 to receive spalled chips 150 from the spall area 15. The chip receiver 320 may be configured with individual storage compartments (not shown) and also with 15 trapdoors (not shown) to allow spalled chips 150 to pass therethrough. The individual storage compartments (not shown) and the trapdoors (not shown) may be operable by an operator using the controller 250 and operator interface 251 to ensure that sought-after minerals 11 are collected in the chip receiver 320 while mining waste is allowed to pass 20 through the trapdoor (not shown) or allowed to drop to a lower drift 17.

Spacing wheels 330 on shock absorbing mounts 331 facilitate movement of the mining array 300 along the work surface 12 and assist in maintaining the desirable predetermined distance 14 between the rotating scanning head 76 and the spall area 15 to facilitate effective spalling (Figure 9) which necessitates that the focal point of the laser beams 83 be upon the spall area 15.

Plural laser drill heads 70 may be carried on the frame 310 and the plural laser drill heads 70 are positioned thereon so that the spall area 15 formed by each laser drill head 70 is immediately adjacent to the spall area 15 of an adjacent laser drill head 70 causing spalling across a larger area, such as when large volumes of ore 11b are being removed.

An x-ray fluorescence emitter/receiver 350, an illumination device 360 and a video camera 370 may be carried by the frame 310. The x-ray fluorescence emitter/receiver 350 emits predetermined wavelength of electromagnetic radiation upon the work surface 12 causing reflectivity, illumination, and luminescence of various desirable sought-after minerals 11 present within the stratum 10. The receiver portion/function of the x-ray fluorescence emitter/receiver 350, such as those manufactured by Olympus Corporation, receives the reflected/emitted electromagnetic radiation from the sought after

mineral 11 and registers the receipt of such reflected electromagnetic radiation which is indicative of the presence and concentration/density of the sought after mineral 11. The presence of the sought after mineral 11 is thereupon operatively communicated to the controller 5 250 and user interface 251 being monitored by an operator. The illumination device 360 provides light that is projected upon the work surface 12 which allows the video camera 370 to record and monitor operations of the spalling generated by the laser drill heads 70. Video information recorded by the video camera 370 is 10 communicated/transmitted to the controller 250 and the user interface 251 for monitoring by an operator at a remote location, typically in the equipment transport vehicle 50.

The physical configuration of the individual plural laser drill heads 70, when mounted on the mining array 300 may be somewhat 15 different than the laser drill heads 70 configuration used for borehole mining (Figure 2) since it is not necessary that the laser drill heads 70 mounted on the mining array 300 to have drive units 220 because the position of the mining array 300 is controlled by the controller 250, the crane mechanism 51 and also by the spacing wheels 330.

20 The pressurized air (not shown) supplied by the source of compressed air 20 is emitted through the air curtain orifice 146 and

onto the work surface 12. The pressurized air (not shown) impacting the work surface 12 cools the spall area 15 immediately after it is irradiated by the laser beam 83 and instantaneously heated to extreme temperatures causing rapid expansion of the stratum 10. The
5 immediate subsequent cooling of the stratum 10 by the pressurized air (not shown) causes rapid contraction of the stratum 10 which leads to the spalling of the work surface 12 and formation of chips 150 which are removed therefrom. It is the rapid extreme heating and rapid
extreme cooling that generates the spalling of the work surface 12.

10 As shown in Figure 9 the mining array 300 is configured for spallation mining in vertical shafts 16, and also in angulated drifts 17 and in winzes 18 where the mining array 300 is movable by gravity, and also by the crane mechanism 51 of the equipment transport vehicle 50. The mining array 300 is therefore movable in two opposing
15 directions, in a first direction by gravity, and in a second direction opposite gravity. The spring wheels 330 maintain the predetermined desirable distance 14 between the rotating scanning heads 76 and the work surface 12 as the mining array 300 is moved in both directions and spallation mining continues.

20 A proximity switch (not shown) carried by the mining array 300 is used to monitor and maintain the predetermined desirable distance 14

from the rotating scanning head 76 of each laser drill head 70 to the work surface 12 for optimum operation, so that the focal point (not shown) of each laser beam 83 irradiates the work surface 12. Movement of the spacing wheels 330 in response to operation of the crane mechanism 51 is computer controlled. Operator control of the video cameras 370, illumination device 360, x-ray fluorescence emitter/receiver 350 and the crane mechanism 51 allows the operator to analyze the direction and width of narrow veins 11a and selectively program the laser drill heads 70 to cut out only the desired mineral 11.

Subsequent passes of the mining array 300 maybe used to remove the remaining stratum 10.

The equipment transport vehicle 50 carries the necessary computers to control the laser drill head 70 operation, the optical mirrors servo system (not shown), face mapping data generated by video cameras 370, the x-ray fluorescence emitter/receiver 350, as well as the operational controls for the pressurized air (not shown), and the chip removal system 200 and chip receiver 320 of the mining array 300. The equipment transport vehicle 50 mounts the necessary number sources of electromagnetic radiation 40 and other operating equipment, such as, but not limited to, fiber optic cables 60a, electronic and electrical cables and compressed air hose and the

associated winches. On board electrical power generation 30, liquid petroleum gas (LPG) tanks to fuel the source of electrical energy 30, source of pressurized air 20 and associated equipment. On board electrical power generation 30, liquid petroleum gas (LPG) or other
5 appropriate material holding tanks (not shown) to fuel the source of electrical energy 30 also supplies power for the equipment transport vehicle 50 drive means 53 and systems (not shown) for operator comfort within the occupant compartment 54.

The apparatus consists of a fiber laser 40a, a flexible cable 60
10 having a fiber optic cable 60a conduit 63 capable of transmitting up to at least 2 kW of optical power over a distance of up to approximately 500 feet as well as a gaseous supply conduit 63 capable of flowing at least approximately 100 CFM at 100 psi, and a shielded conduit 63 capable of transmitting sufficient electrical power over the distance of
15 approximately 500 feet to operate servo controlled azimuth drives 105 and positional location devices (not shown), illumination devices 360, video cameras 370, electronic controls and signal return tables for the mining array 300 components.

The laser beam 83 is transmitted through the fiber-optic cable
20 60a from the first end portion 61 which communicates with the fiber laser 40a, to the second end portion 62 which communicates with the

collimator 77 within the laser drill head 70. A high power fiber coupler 64 interconnects the first end portion 61 of the fiber-optic cable 60a with the fiber laser 40a and a second high power fiber coupler 64 interconnects the second end portion 62 of the fiber-optic cable 60a
5 with a collimator 77 carried within the laser drill head 70 . The collimator 77 encloses the beam expanding optical elements (not shown) and beam collimating optical elements (not shown). Cooling orifices 125 communicating with the source of compressed air 20 operatively communicate with the collimator 77 so that pressurized
10 cooling air flows onto and around the optical elements to provide cooling.

As the expanded, collimated laser beam 83 exits the collimator 77, which is carried within the laser drill head 70, the laser beam 83 is directed to a folding mirror 90 which is coated with a highly reflective
15 (proprietary to the supplier) coating in a wavelength of the laser beam 83. The folding mirror 90 is mounted on a set of pivots (not shown) and a servo controlled azimuth drive 105 to allow the position and angle of the folding mirror 90 to be adjusted as necessary to rapidly translate the laser beam 83 one half of a beam diameter. The folding
20 mirror 90 is electronically driven by the controller 250 such that its frequency of translation can be altered either by a predetermined

controller 250 control or based upon feedback from other instrumentation. Control software (not shown) will also provide fine control over the translation of the folding mirror 90 to manage the total travel of the laser beam 83 on the spall area 15.

5 The laser beam 83 is then directed to the oscillating mirror 95 which is also adjustably mounted on a servo controlled azimuth drive 105 and which is also coated with a highly reflective coating in the wavelength of the laser beam 83.

10 The laser beam 83 is then directed to a scanning mirror 100 which is similarly coated with a highly reflective coating in the wavelength of the laser beam 83 and which is also mounted on a servo controlled azimuth drive 105.

15 Finally, the laser beam 83 passes through the protective transparent window 80 which is protected by the air curtain (not shown) of pressurized air to allow the laser beam 83 to irradiate the spall area 15. All three of the mirrors 90, 95, 100 are separately mounted on servo controlled azimuth drives 105 which communicate with the controller 250. The laser beam 83 is thus able to be directed, based on the diameter of the collimated laser beam 83 upon the
20 selected spall area 15. All three mirrors 90, 95, 100 receive a stream of cooling gas which is supplied by the cooling orifices 125 directed upon

the mirrors 90, 95, 100. The cooling gas is subsequently exhausted from the laser drill head 70 to assist in forming the air curtain (not shown) exteriorly of the protective transparent window 80. An additional high-pressure air nozzle (not shown) may be carried proximate to the air curtain orifice 146 to direct a stream of cooling gas upon the spall area 15 to deflect chips 150 and to absorb any excess vapors.

OPERATION

10 The operation of the described embodiment of the present invention is believed to be readily apparent and is briefly described at this point.

In use, an appropriately sized mining array 300 will be lowered from the upper drift 17. The laser beams 83, directed by the rotating scan heads 76 will irradiate the work surface 12 and begin cutting/spalling chips 150 which are collected into a chip receiver 320 and subsequently may be dropped by means of gravity to a lower drift 17. Ore 11b may be separated from waste in the chip receiver 320, by selective cutting. Waste material may be retained, mixed or sprayed with cement or a resin additive, and delivered directly behind a form to create an "in-place" backfill system.

One aspect of the instant method of comprises generating and delivering a laser beam 83 to a working surface 12 of a geological stratum 10 having a sought after mineral 11 to be removed; moving the laser beam 83 about three perpendicular axes so that a focal point
5 of the laser beam 83 moves across the working surface 12, and rapidly increases the surface temperature of the working surface 12; providing a source of a cooling media 20, and delivering the cooling media to the working surface 12 so as to rapidly cool the working surface 12 subsequent to the rapid surface temperature increase generated by the
10 laser beam 83 so as to effect a fracturing of the working surface 12 and to generate a plurality of chips 150 from the working surface 12; and removing the chips 150 spalled from the working surface 12.

A second aspect of the instant method of mining comprises: providing a geological stratum 10 having a sought after mineral 11 to
15 be removed; delivering a laser beam 83 to a working surface 12 of the geological stratum 10 and which has a power output which is sufficient to spall small chips 150 of the working surface 12 of the geological stratum 10; moving the laser beam 83 along a predetermined path of travel across the working surface 12, and wherein the delivery of the
20 laser beam 83 to the working surface 12 increases the surface temperature of the working surface 12; providing a source of a cooling

media 20, and delivering the cooling media to the working surface 12 so as to maintain the working surface 12 temperature below a temperature which encourages spalling; removing at least in part, a portion of the spalled chips 150 generated from the working surface
5 12; and delivering the removed spalled chips 150 to a remote area.

A third aspect of the instant method of mining comprises providing a geological stratum 10 having a sought after mineral 11; providing a working surface 12 of the stratum 10 and upon which the method of mining may be operated; providing sources of compressed
10 air 20, electrical energy 30 and electromagnetic radiation 40; generating a laser beam 83 with the sources of electricity 30 and electromagnetic radiation 40, and which has a power sufficient to cause a spalling of the stratum 10 and sought after mineral 11 forming the work surface 12; providing a flexible cable 60 having a first end
15 portion 61, and a second end portion 62, and wherein the first end portion 61 operatively communicates with the source of electromagnetic radiation 40, the source of compressed air 20, and the source of electrical energy 30; delivering the laser beam 83 to the first end portion 61 of the flexible cable 60 for transmission therealong;
20 providing a laser drill head 70 having a first end portion 73 and a second end portion 74, and wherein the second end portion 74 of the

laser drill head 70 operatively communicates with the second end portion 62 of the flexible cable 60 and further receives the electromagnetic radiation from the source of electromagnetic radiation 40, the laser beam 83 which the flexible cable 60 receives, and passes therealong, the compressed air from the source of compressed air 20, and the electrical energy from the source of electrical energy 30; providing a rotating scanning head 76 at the first end portion 73 of the laser drill head 70 and which operatively communicates with the source of electromagnetic radiation 40, and wherein the rotating scanning head 76 has a protective and transparent window 80 at a first end portion 73, and plural, internal, reflective optical elements 85 which are located in predetermined spaced relation relative to the protective transparent window 80 and which are further contained within a body 70 of the laser drill head 70, and wherein the reflective optical elements 85 are individually controllably movable to transmit the laser beam 83 through the protective transparent window 80, and onto a spall area 15 of the work surface 12, and which is proximate to the rotating scanning head 76, and wherein the laser beam 83 is moved in a given pattern having a predetermined scanning time, and a predetermined dwell time, so as to cause spalling of the stratum 10 and which generates a multiplicity of spalled chips 150, and a removal

of the sought after mineral 11 from the spall area 15; delivering the compressed air to the rotating scanning head 76 so as to both cool the internal, reflective optical elements 85, and the spall area 15 which is being irradiated by the laser beam 83 so as to thermally control the

5 stratum 10 and sought after mineral 11, and which further promotes the cooling of the spall area 15 while inhibiting the melting and vaporization of the stratum 10 and the sought after mineral 11; removing the spalled chips 150 away from the spall area 15 by the use of the source of compressed air 20; providing a removal system 200

10 having an evacuation port 130 which is proximate to the rotating scanning head 76 for evacuating the spalled chips 150 from the spall area 15, and for propelling the spalled chips 150 toward the second end portion 75 of the laser drill head 70, and to a remote location for collection and processing; providing a drive unit 220 to move the laser

15 drill head 70 along a predetermined path of travel relative to the work surface 12, and to further maintain a predetermined desirable distance 14 between the rotating scanning head 70 and the working surface 12 so as to facilitate effective spalling and the generation of the spalled chips 150; and providing a controller 250 operatively communicating

20 with, and controllably coupled to the laser drill head 70, the drive unit 220, the source of electromagnetic radiation 40, the source of

compressed air 20, the source of electrical energy 30, and the removal system 200, and wherein the controller 250 is located remotely relative to the laser drill head 70, and further controls the operation of the laser drill head 70, the delivery of the compressed air, and the removal
5 of the spalled chips 150 by way of the removal system 200.

This disclosure and description has set out various features, functions, methods capabilities, uses and other aspects of our invention. This has been done with regard to the currently preferred embodiments thereof. Time and further development may change the
10 manner in which the various aspects are implemented.

The scope of protection accorded the inventions as defined by the claims is not intended to be limited to the specific sizes, shapes, features or other aspects of the currently preferred embodiments shown and described. The claimed inventions may be implemented or
15 embodied in other forms while still being within the concepts shown, disclosed, described and claimed herein. Also included are equivalents of the inventions which can be made without departing from the scope of concepts properly protected hereby.

20 [REMAINDER OF THIS PAGE INTENTIONALLY LEFT BLANK]

CLAIMS

What is claimed is:

1. A method of mining, comprising:
 - generating and delivering a laser beam to a working surface of a
 - 5 geological strata having a sought after mineral to be removed;
 - moving the laser beam about three perpendicular axes so that a focal point of the laser beam moves across the working surface, and rapidly increases the surface temperature of the working surface;
 - providing a source of a cooling media, and delivering the cooling
 - 10 media to the working surface so as to rapidly cool the working surface subsequent to the rapid surface temperature increase generated by the laser beam so as to effect a fracturing of the working surface and to generate a plurality of chips from the working surface; and
 - removing the chips spalled from the working surface.

- 15 2. A method of mining, comprising:
 - providing a geological strata having a sought after mineral to be removed;
 - delivering a laser beam to a working surface of the geological strata
 - 20 and which has a power output which is sufficient to spall small chips of the working surface of the geological strata;

moving the laser beam along a predetermined path of travel across the working surface, and wherein the delivery of the laser beam to the working surface increases the surface temperature of the working surface;

5 providing a source of a cooling media, and delivering the cooling media to the working surface so as to maintain the working surface temperature below a temperature which discourages spalling;

removing at least in part, a portion of the spalled chips generated from the working surface; and

delivering the removed spalled chips to a remote area.

10

3. A method of mining comprising:

providing a stratum having a sought after mineral;

providing a working surface of the stratum and upon which the method of mining may be operated;

15 providing sources of compressed air, electrical energy and electromagnetic radiation;

generating a laser beam with the sources of electricity and electromagnetic radiation, and which has a power sufficient to cause a spalling of the stratum and sought after mineral forming the work surface;

20 providing a flexible cable having a first end portion, and a second end portion, and wherein the first end portion operatively communicates

with the source of electromagnetic radiation, the source of compressed air, and the source of electrical energy;

delivering the laser beam to the first end portion of the flexible cable for transmission therealong;

5 providing a laser drill head having a first end portion and a second end portion, and wherein the second end portion of the laser drill head operatively communicates with the second end of the flexible cable and further receives the electromagnetic radiation from the source of electromagnetic radiation, the laser beam which the flexible cable receives,
10 and passes therealong, the compressed air from the source of compressed air, and the electrical energy from the source of electrical energy;

providing a rotating scanning head at the first end portion of the laser drill head and which operatively communicates with the source of electromagnetic radiation, and wherein the rotating scanning head has a
15 protective and transparent window at a first end portion, and plural, internal, reflective optical elements which are located in predetermined spaced relation relative to the protective transparent window and which are further contained within a body of the rotating scan head, and wherein the reflective optical elements are individually controllably movable to
20 transmit the laser beam through the protective transparent window, and onto a spall area of the work surface, and which is proximate to the

rotating scanning head, and wherein the laser beam is moved in a given pattern having a predetermined scanning time, and a predetermined dwell time, so as to cause spalling of the stratum and which generates a multiplicity of spalled chips, and a removal of the sought after mineral

5 from the spall area;

delivering the compressed air to the rotating scanning head so as to both cool the internal, reflective optical elements, and the spall area which is being irradiated by the laser beam so as to thermally control the stratum and sought after mineral, and which further promotes the cooling of the

10 spall area while inhibiting the melting and vaporization of the stratum and the sought after mineral;

removing the spalled chips away from the spall area by the use of the source of compressed air;

15 providing a removal system having an evacuation port which is proximate to the rotating scanning head for evacuating the spalled chips from the spall area, and for propelling the spalled chips toward the second end of the laser drill head, and to a remote location for collection and processing;

20 providing a drive unit to move the laser drill head along a predetermined path of travel relative to the work surface, and to further maintain a predetermined desirable distance between the rotating

scanning head and the working surface so as to facilitate effective spalling and the generation of the spalled chips; and

providing a controller operatively communicating with, and controllably coupled to the laser drill head, the drive unit, the source of
5 electromagnetic radiation, the source of compressed air, the source of electrical energy, and the removal system, and wherein the controller is located remotely relative to the laser drill head, and further controls the operation of the laser drill head, the delivery of the compressed air, and the removal of the spalled chips by way of the removal system.

10

4. The method of mining as claimed in Claim 3 and wherein the sought after mineral is contained within a vein.

15 5. The method of mining as claimed in Claim 3 and wherein the sought after mineral is within an ore.

6. The method of mining as claimed in Claim 3 and wherein the working surface is vertical.

20 7. The method of mining as claimed in Claim 3 and wherein the working surface is horizontal.

8. The method of mining as claimed in Claim 3 and wherein the working surface is angular.

5 9. The method of mining as claimed in Claim 3 and wherein the working surface is in a shaft.

10. The method of mining as claimed in Claim 3 and wherein the working surface is in a drift.

10

11. The method of mining as claimed in Claim 3 and wherein the working surface is in a winze.

12. The method of mining as claimed in Claim 3 and wherein the
15 source of electromagnetic radiation generates a laser beam having
between approximately 1.4 kW of power and approximately 2.4 kW of
power.

13. The method of mining as claimed in Claim 3 and wherein the
20 source of electromagnetic radiation generates a laser beam having a power
of about 1.6 kW to about 2.0 kW.

14. The method of mining as claimed in Claim 3 and wherein the source of electromagnetic radiation is a fiber laser.

5 15. The method of mining as claimed in Claim 3 and wherein the flexible cable has multiple lumens.

16. The method of mining as claimed in Claim 3 and wherein the flexible cable is an optical fiber.

10

17. The method of mining as claimed in Claim 3 and wherein the spall area is within a semi-hemispherical volume.

18. The method of mining as claimed in Claim 3 and wherein the spall area has a radius of about three inches to about six feet.

15

19. The method of mining as claimed in Claim 3 and wherein the drive unit is a transverse drive which moves the laser drill head longitudinally relative to the work surface, and the spall area so as to maintain a predetermined desirable distance between the rotating scan head and the spall area.

20

20. The method of mining as claimed in Claim 3 and further comprising a face attachment which releasably communicates with the working surface and the laser drill head so as to positionally support the
5 laser drill head relative to the working surface.

21. The method of mining as claimed in Claim 3 and wherein the internal reflective optical elements comprise plural cooperating mirrors, and wherein each cooperating mirror is individually movable using an
10 azimuth drive, and wherein the cooperating mirrors include a first folding mirror; a second oscillating mirror; and a third diverting mirror, and wherein the third diverting mirror transmits the laser beam through the transparent window and along an elevation of about plus 22.5 degrees and
minus, 22.5 degrees while the rotating scanning head simultaneously
15 rotates and wherein the rotation of the scanning head generates a semi-hemispherical shaped spall area.

22. The method of mining as claimed in Claim 3 and wherein the internal reflective optical elements within the scan head are cooled by the
20 stream of compressed air.

23. The method of mining as claimed in Claim 3 and wherein a portion of the compressed air delivered to the rotating scan head is emitted through a cooling orifice which is proximate to the protective transparent window, and wherein the emitted compressed air forms a protective air curtain over and about the transparent window.

5

24. The method of mining as claimed in Claim 3 and wherein plural laser drill heads are carried in a predetermined spaced relationship on a mining array so as to cause spalling over a larger area of working surface.

10

25. The method of mining as claimed in Claim 24 and further comprising an X-Ray fluorescence (XRF) emitter/receiver and which is carried on the mining array, and which scans the strata for the desired mineral, and further receives fluorescence emitted by the strata, and the desired mineral, and wherein the X-Ray fluorescence (XRF) emitter/receiver communicates with the controller so as to allow an operator to direct the mining array to the desired mineral.

15

26. The method of mining as claimed in Claim 24 and further comprising an illumination device and a video camera on the mining array, and wherein the method further comprises illuminating the work surface

20

with the illumination device, and then video recording the spalling so as to provide a video recording of the spalling to the controller; visually monitoring the spalling; and adjusting as necessary, the operation of the mining array.

5

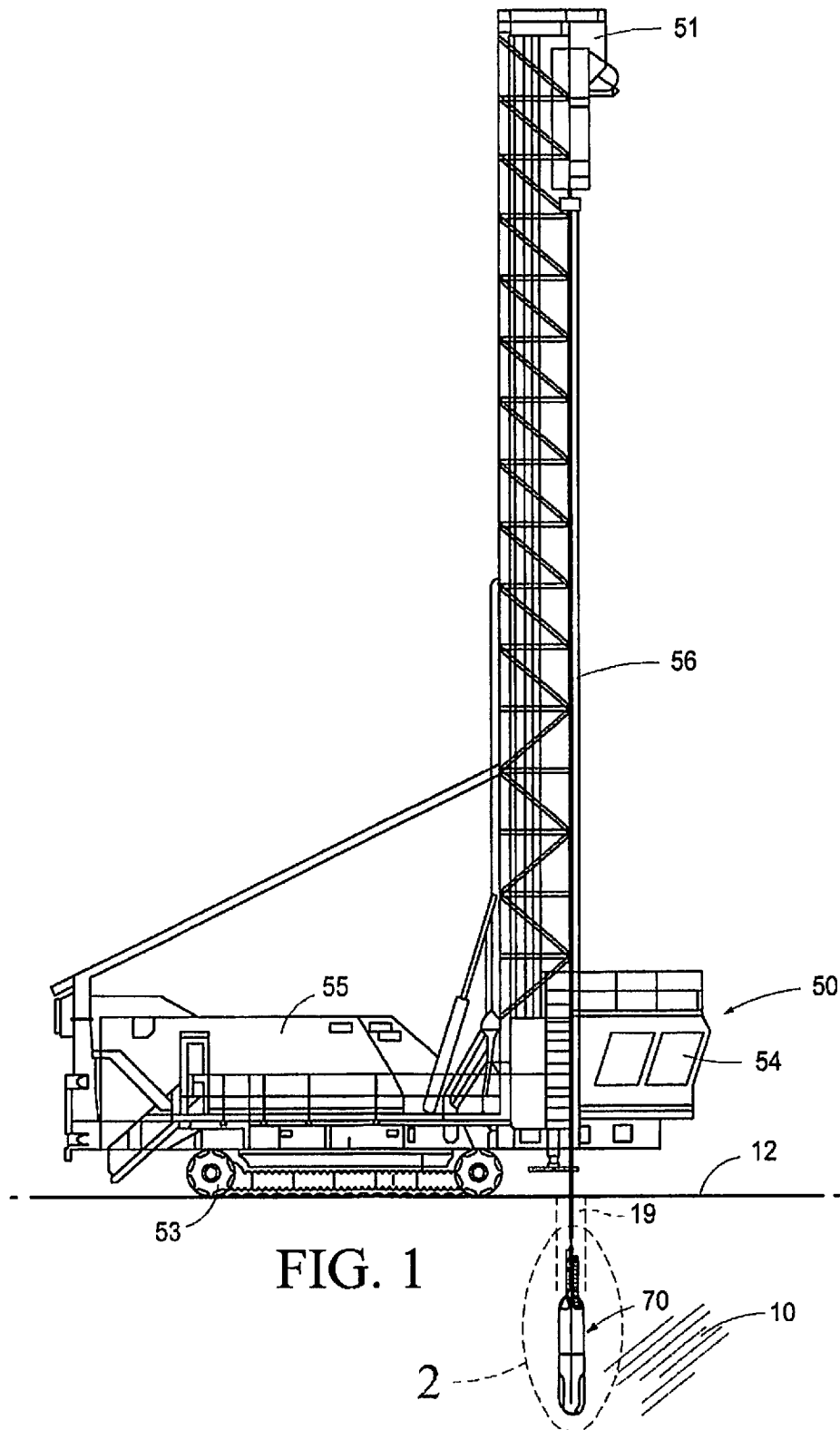


FIG. 1

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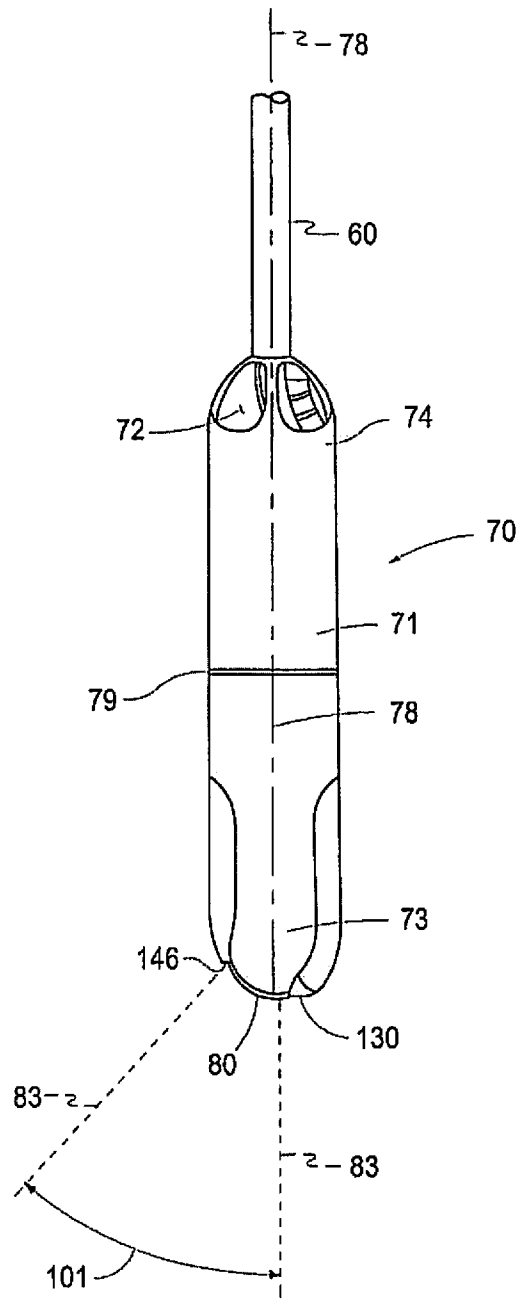


FIG. 2

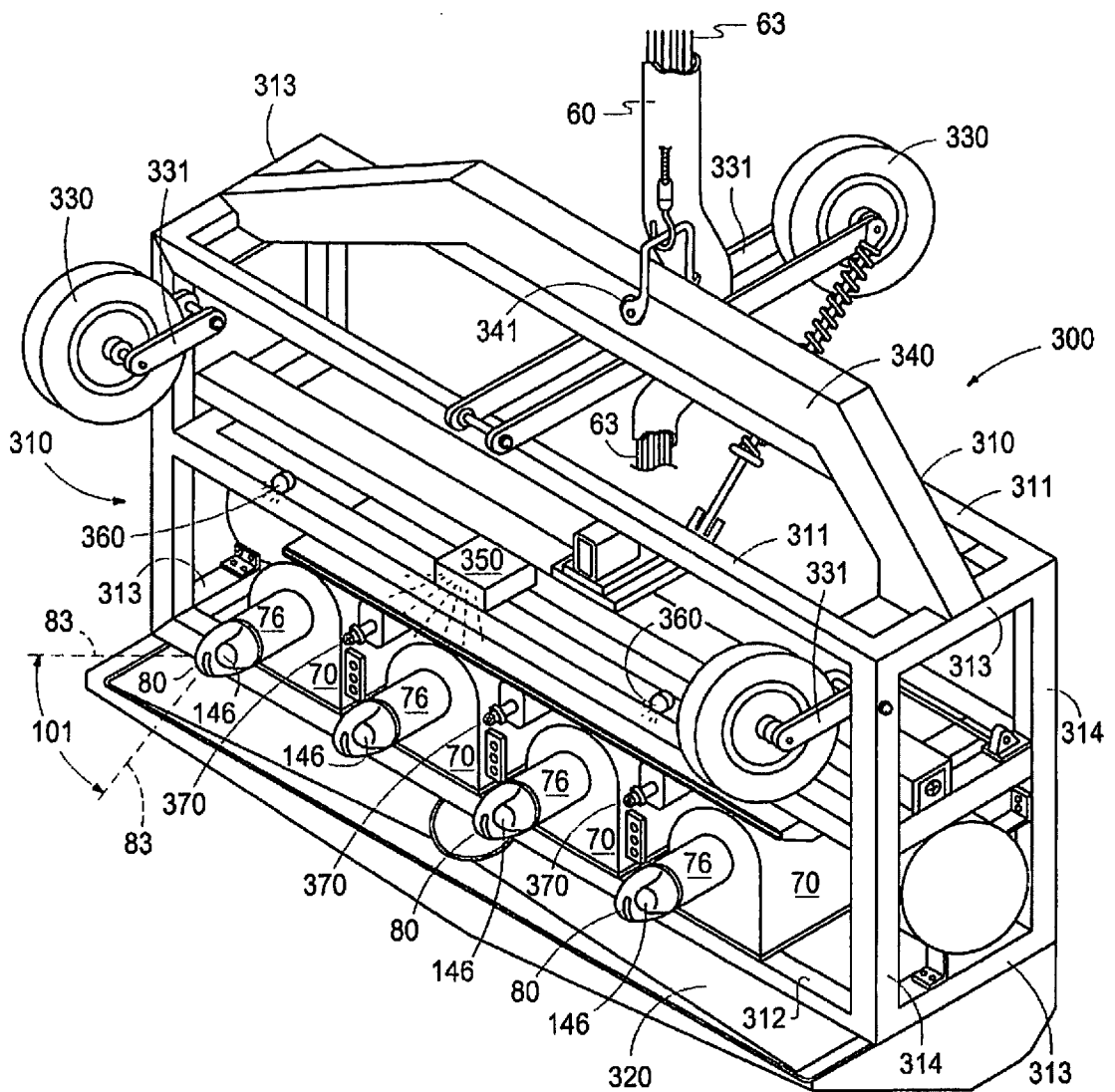


FIG. 3

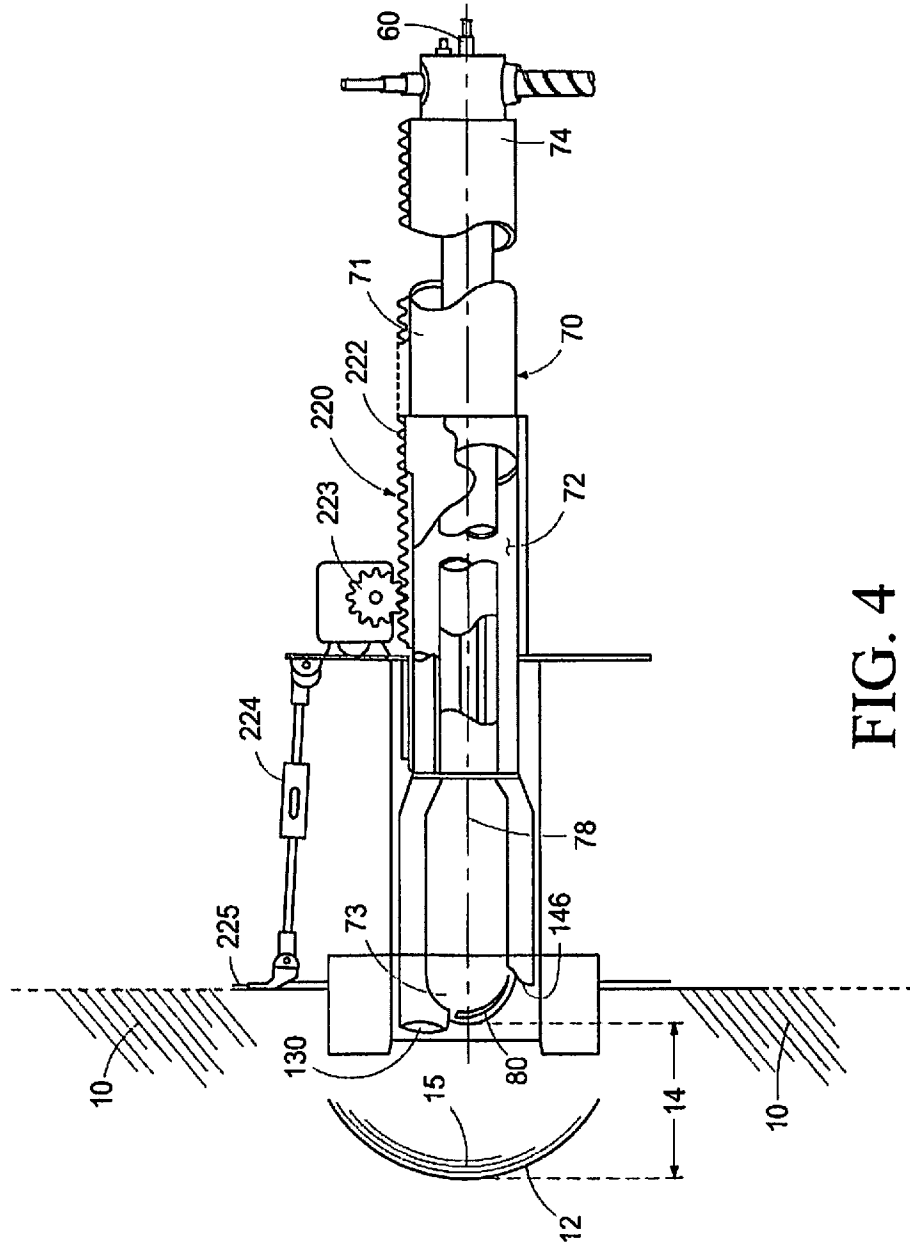


FIG. 4

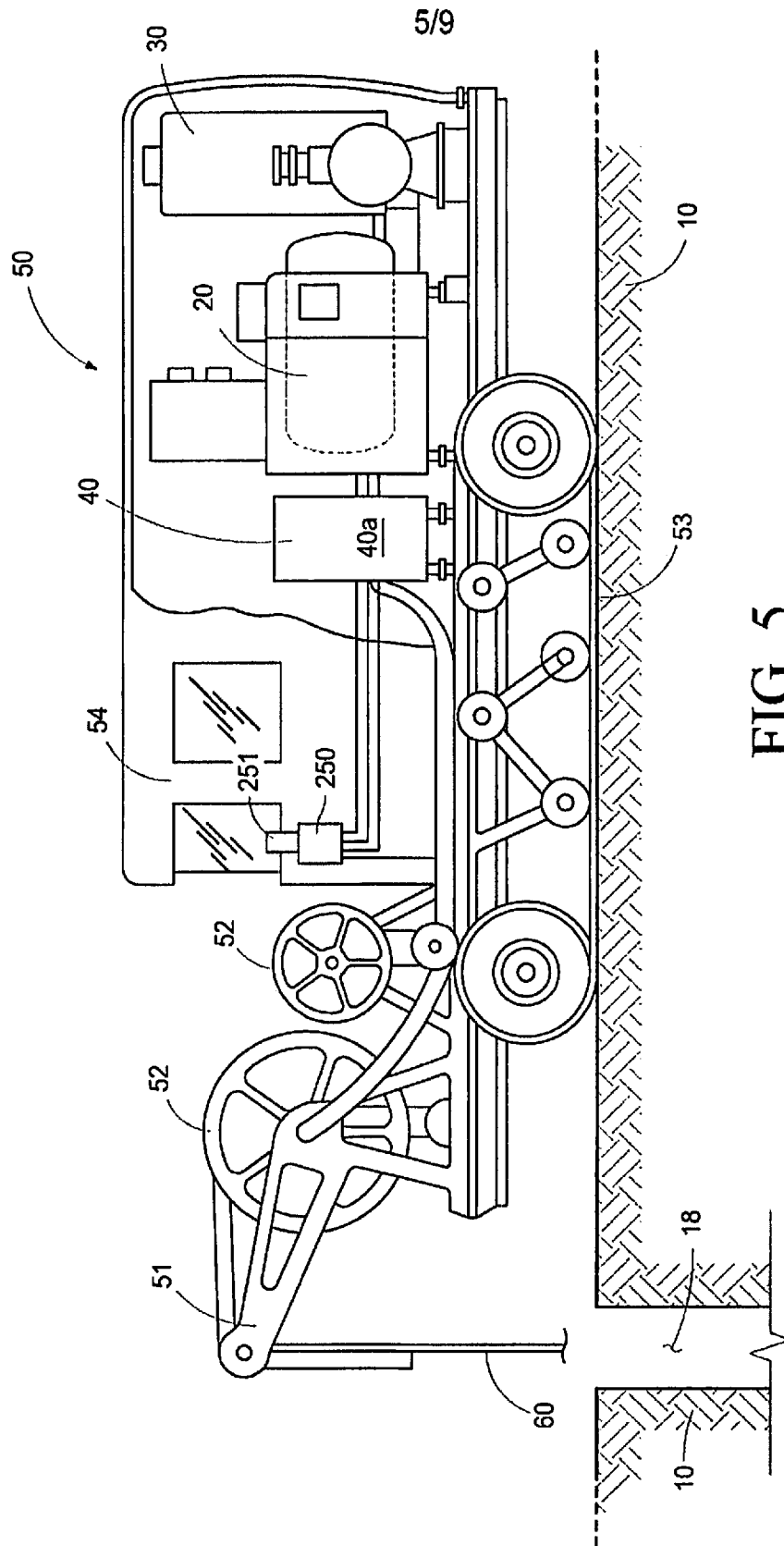


FIG. 5

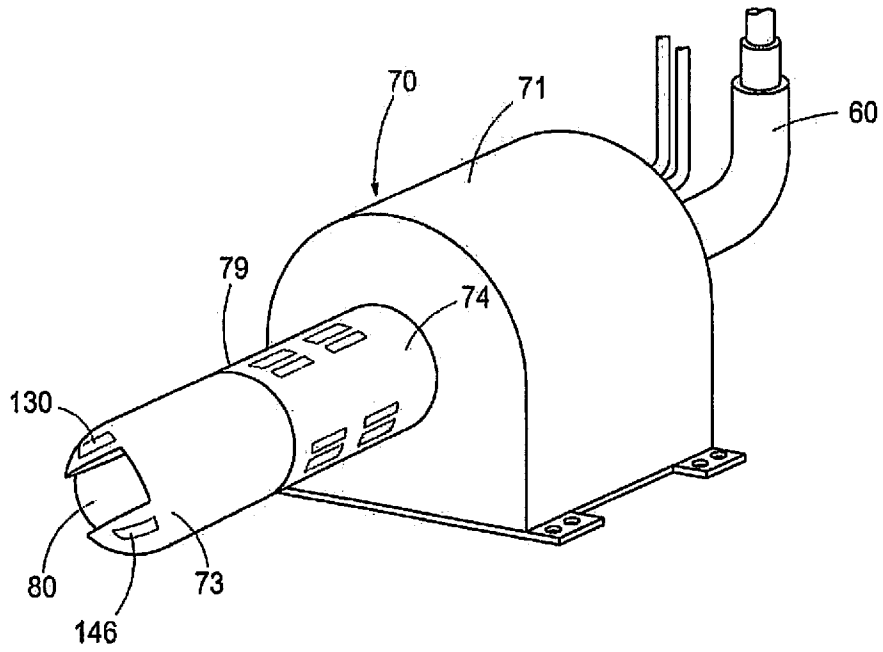


FIG. 6

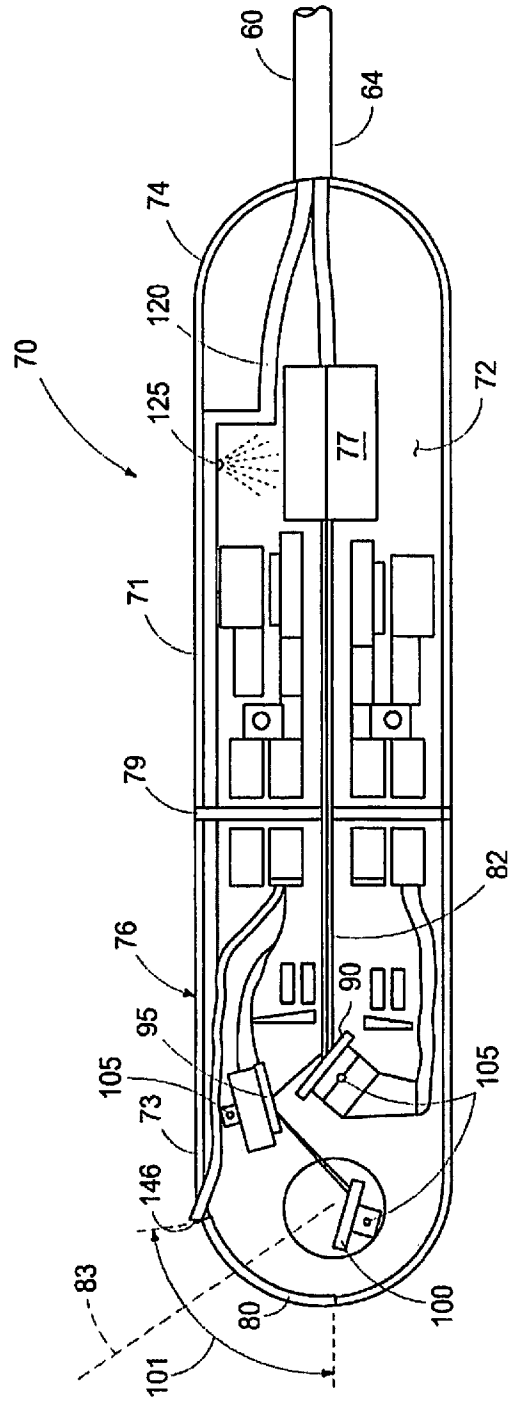
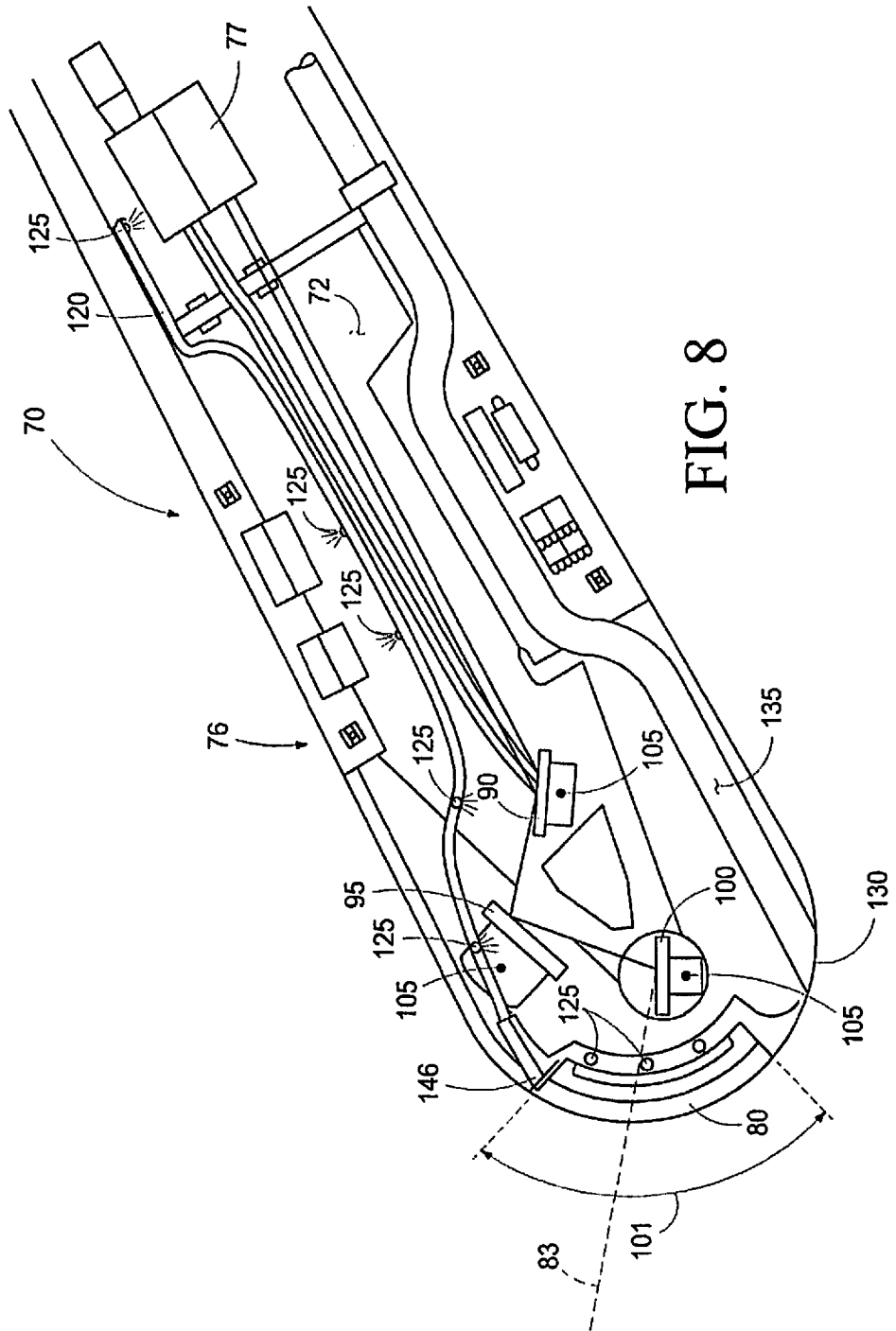


FIG. 7



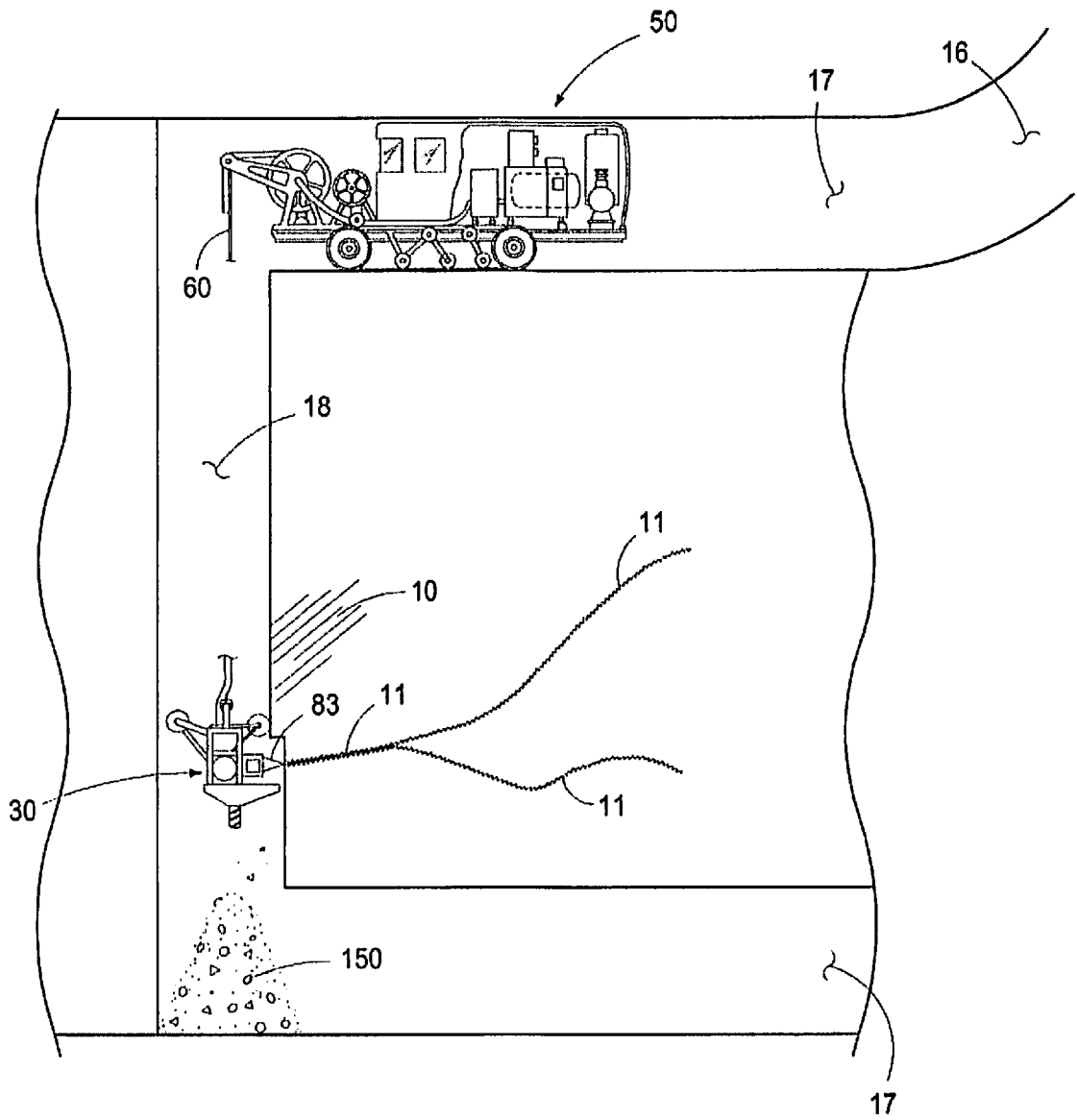


FIG. 9

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2016/062004

A. CLASSIFICATION OF SUBJECT MATTER IPC(8) - B23K 26/38; B23K 26/14; B23K 26/16; B23K 26/36; E21D 9/10; E21D 9/12 (2016.01) CPC - B23K 26/38; B23K 26/14; B23K 26/16; B23K 26/36; E21D 9/1073; E21D 9/12 (2016.11) According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) IPC - B23K 26/14; B23K 26/16; B23K 26/36; B23K 26/38; E21D 9/10; E21D 9/12 CPC - B23K 26/14; B23K 26/16; B23K 26/36; B23K 26/38; E21D 9/1073; E21D 9/12 Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched USPC - 166/57; 175/11; 175/16; 219/121.67; 219/121.72; 250/254; 299/10; 299/14; 299/29 (keyword delimited) Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) Orbit, Google Patents, Google Scholar, Google Search terms used: method, mining, generator, compressor, air, curtain, laser, beam, working, surface, geological, strata, mineral, ore, vein, perpendicular, axes, rotating, scanning, head, flexible, cable, rapid, temperature, increase, cooling, media, chips, spall, electrical		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2010/0041102 A1 (RINZLER et al) 25 February 2010 (25.02.2010) entire document	1, 2
A	US 2014/0231398 A1 (LAND et al) 21 August 2014 (21.08.2014) entire document	1-26
A	US 6,755,262 B2 (PARKER) 29 June 2004 (29.06.2004) entire document	1-26
A	US 4,266,609 A (ROM et al) 12 May 1981 (12.05.1981) entire document	1-26
<input type="checkbox"/> Further documents are listed in the continuation of Box C. <input type="checkbox"/> See patent family annex.		
* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "I," 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 when the document is taken alone "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		
Date of the actual completion of the international search 03 January 2017		Date of mailing of the international search report 24 JAN 2017
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, VA 22313-1450 Facsimile No. 571-273-8300		Authorized officer Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774