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Aug. 19, 1969 A. A. VENGHIATTIS 3,461,964

WELL PERFORATING APPARATUS AND METHOD

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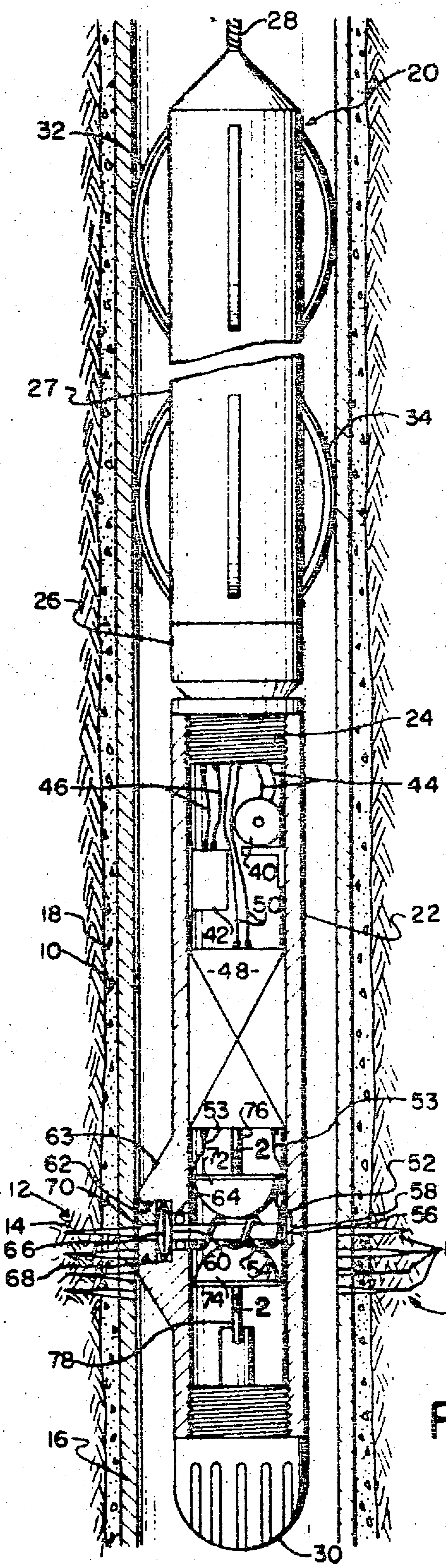

FIG. 1

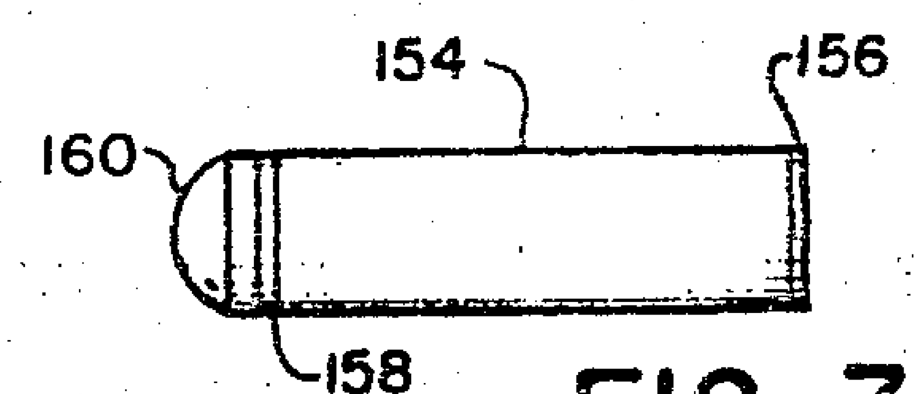

FIG. 3

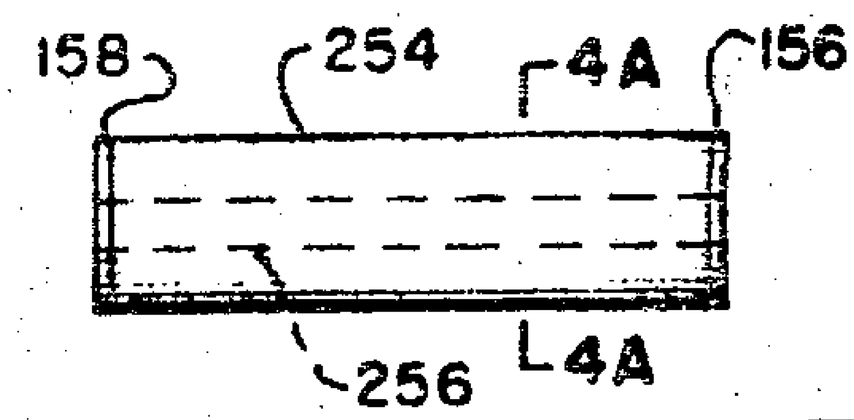

FIG. 4

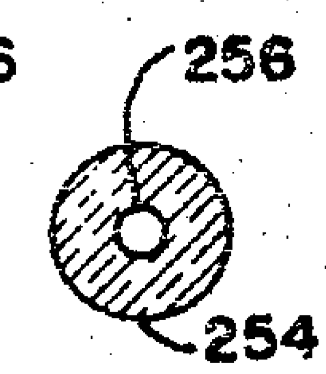

FIG. 4A

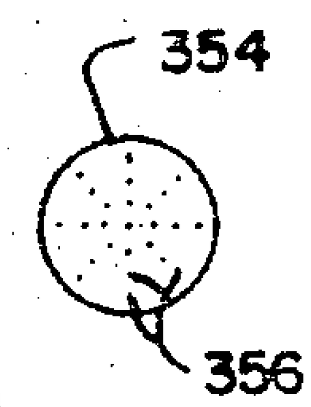

FIG. 5A

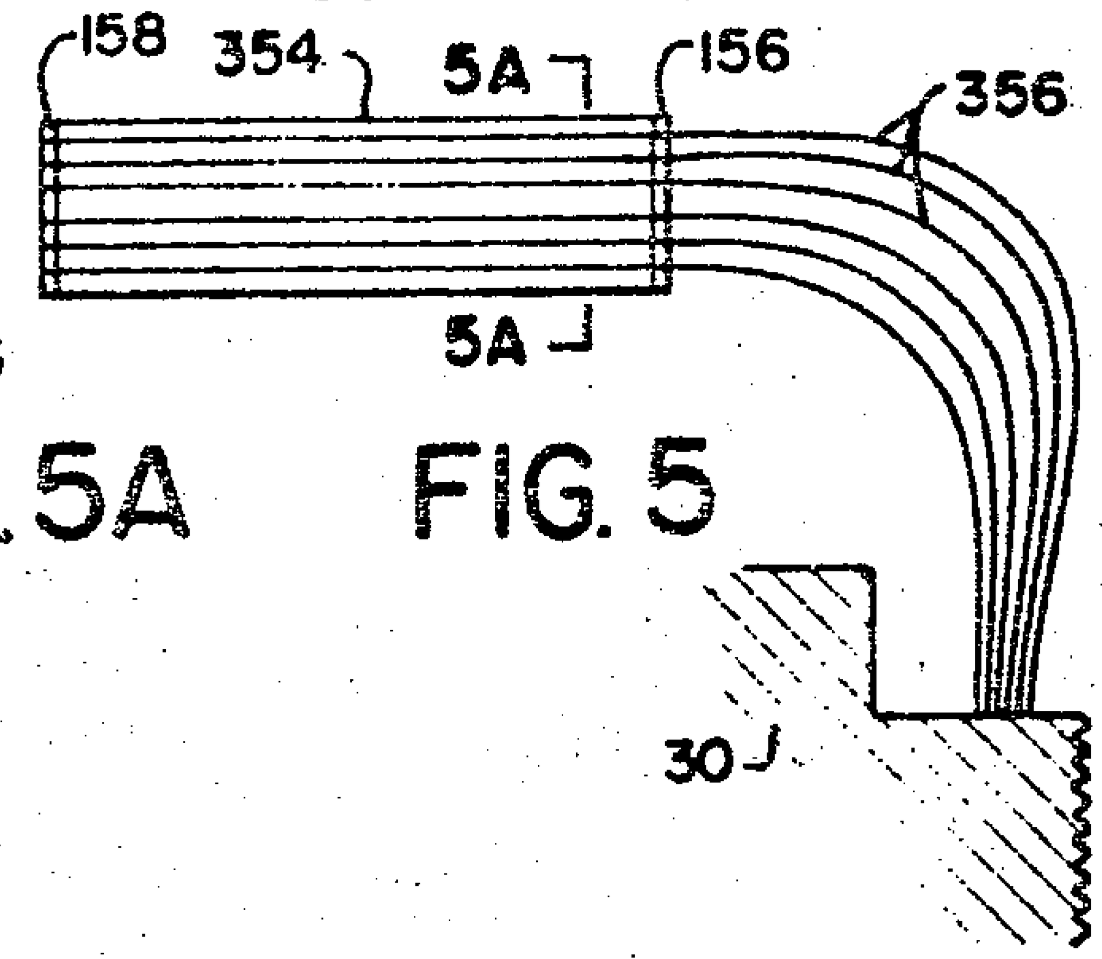

FIG. 5

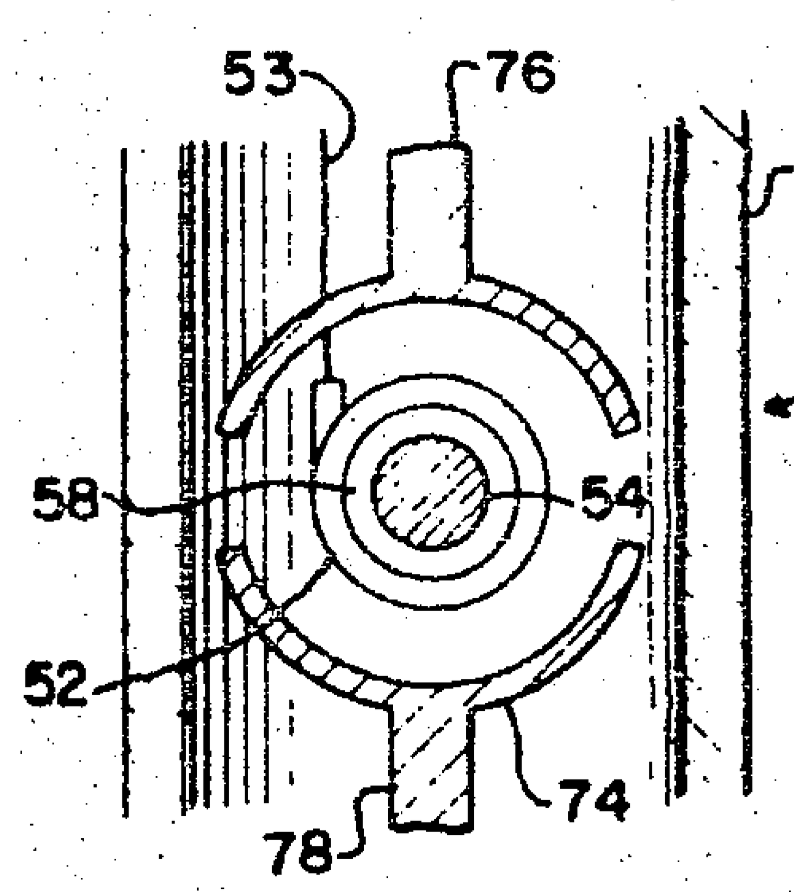

FIG. 2

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WELL PERFORATING APPARATUS AND METHOD

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U.S. Cl. 166—297 14 Claims

ABSTRACT OF THE DISCLOSURE

Apparatus for forming perforations or foraminous screens, in situ, in the wall of well bores or the like wherein the apparatus includes a quantum device arranged to emit a beam of coherent, monochromatic electromagnetic energy of sufficient intensity to penetrate the casing and/or tubing and, where applicable, formations surrounding the well bore. Specifically, the apparatus includes a laser device that is movable in the well bore that can be discharged when desired to selectively form the perforations.

This invention relates generally to improved apparatus and methods useful in oil and gas wells and the like for perforating formations surrounding the well bore. More particularly, but not by way of limitation, this invention relates to an improved perforating apparatus and method utilizing electromagnetic energy to form the perforations.

After a productive or suspected productive zone has been reached during the drilling of oil or gas wells or the like, the usual procedure is to line the well bore with a metal pipe or "casing" as it is known in the trade. Due to the difference in size between the well bore and the exterior of the casing and due to the irregularity of the well bore, cementitious material is generally pumped into at least a portion of the annular space between the well bore and casing to permanently set the casing therein and to prevent migration of fluids from one zone to another through the annular space. As might be expected, the cementitious material and the casing completely block the productive formation so that no fluids can be produced into the casing. To permit the production of fluids from the productive zone into the interior of the casing, the casing and cementitious material adjacent the productive zone must be perforated.

Presently, bullet or shaped charge perforating guns have been lowered into the casing and fired at a point adjacent the productive zone. The bullets and/or the jets perforate the casing, the cementitious material, and extend into the formation surrounding the well bore forming openings or passageways therein that permit the migration of fluid from the formation into the interior of the casing.

Bullet perforators have been reasonably effective in forming the perforations, but the arrangement of the perforations has been determined by the configuration of the gun with little deviation being possible. Similarly, jet perforators have been effective in forming the perforations. However, the arrangement of the perforations will be in accordance with the configuration of the carrier for the shaped charges.

When the perforated formation consists of an unconsolidated sand, the perforations are usually so large as compared to the grain size of the sand to permit migration of the sand with well fluids into the interior of the casing. Manifestly, if a sufficient quantity of sand enters

the casing, serious damage or destruction of equipment operating in the casing may result. Therefore, special equipment and methods are generally utilized when unconsolidated sands are to be perforated.

Preperforated or slotted liners and screens have been run as part of the casing into the well bore and positioned adjacent the sand formation. The use of such screens or liners limits production to a specified zone. If it is decided to produce other zones at a later time, the casing is generally perforated at such other zones by conventional means and, if the formation is unconsolidated, the previously discussed difficulties are again encountered.

For some time, lasers and similar quantum devices have been utilized to form holes in metal, and other hard materials. The holes formed have been very small in diameter and, therefore, the application of such devices to perforate oil wells and the like has been believed to be impractical.

Furthermore, well bore conditions, that is, the fluids, heat, pressures and small available area therein provide less than an optimum operating environment for the quantum devices. Generally, this invention provides a quantum device operable in such environmental conditions to perforate the casing, cementitious material, and the formation forming, in situ, a foraminous screen that effectively inhibits the flow of sand into the casing.

More specifically, this invention provides improved perforating apparatus for use in a well bore or the like that comprises: a quantum device movable in the well bore and including power supply means and an energy emission portion operably associated with the power supply means; the emission portion being oriented generally toward a portion of the wall surrounding the well bore and arranged, when energized by the power supply means, to emit a beam of coherent, monochromatic electromagnetic energy of sufficient intensity to disintegrate the portion of the wall engaged thereby, whereby an opening or passageway is formed therein intersecting the well bore; and, means connected with the quantum device for moving the device along the well bore.

One object of the invention is to provide an improved perforating apparatus that can be repeatedly fired to form the desired number of passageways or perforations in the wall of the well bore without removing the perforating apparatus therefrom.

Another object of the invention is to provide improved apparatus wherein electromagnetic energy is utilized to perforate the formation surrounding the well bore.

A further object of the invention is to provide an improved perforating apparatus that is completely retrievable.

Still another object of the invention is to provide an improved perforating apparatus that may be repeatedly discharged and moved in the well bore to provide any desired arrangement of perforations.

An additional object of the invention is to provide an improved perforating apparatus that has an extended service life.

One further object of the invention is to provide an improved method of perforating the formation surrounding well bores that utilizes an energy beam for forming the transversely extending passageways.

The foregoing and additional objects and advantages of the invention will become more apparent as the following detailed description is read in conjunction with the accompanying drawings wherein like reference characters denote like parts in all views and wherein:

FIGURE 1 is a vertical cross-sectional view of a portion of a cased well bore illustrating perforating apparatus constructed in accordance with the invention disposed therein;

FIGURE 2 is an enlarged cross-sectional view taken substantially along the line 2—2 of FIGURE 1;

FIGURE 3 is an enlarged view illustrating another embodiment of crystal suitable for use in the perforating apparatus illustrated in FIGURE 1;

FIGURE 4 is an enlarged view illustrating still another embodiment of crystal suitable for use in the perforating apparatus illustrated in FIGURE 1;

FIGURE 4A is a cross-sectional view taken generally along the line 4A—4A of FIGURE 4;

FIGURE 5 is an enlarged view illustrating still another embodiment of crystal suitable for use in the perforating apparatus illustrated in FIGURE 1; and

FIGURE 5A is an end view of the crystal shown in FIGURE 5.

Referring to the drawing and to FIGURE 1 in particular, a well bore **10** extends through a formation **12** that is to be perforated as illustrated by the perforations **14**. A casing **16** is disposed in the well bore **10** and the annular space between the exterior of the casing **16** and the wall of the well bore **10** is filled with a cementitious material **18**.

A perforating apparatus constructed in accordance with the invention and generally designated by the reference character **20** is disposed in the interior of the casing **16**. The perforating apparatus **20** includes a tubular body **22** threadedly connected at its upper end with an adapter **24**. The adapter **24** is operably connected with a motor **26** that is arranged to rotate the body **22** relative to the casing **16**. The motor **26** is connected with a centralizer assembly **27**. A cable **28** is connected with the centralizer assembly **27** and extends to the surface of the well.

Although not shown, the cable **28** includes a structural member having sufficient strength to support the perforating apparatus **20** in the well bore **10** and a plurality of electrical conductors for purposes that will become more apparent hereinafter. It should also be pointed out that appropriate seals may be provided at the various threaded connections as desired or required to prevent the entrance of well fluids into the perforating apparatus **20**.

At its lower end, the tubular body **22** is threadedly connected with a plug **30**. The plug **30**, in the preferred form of the invention, is constructed from a thermally conductive material, such as copper, whereby the plug **30** functions as a heat sink for reasons that also will become more fully apparent as the following description proceeds. Manifestly, suitable seals may be provided at the threaded connection between the plug **30** and the tubular body **22** to prevent the entrance of fluid into the interior of the tubular body **22**.

In a manner well known to those skilled in the well tool art, vertically extending, upper bow springs **32**, forming part of the centralizer assembly **27**, are arranged on a 120° spacing in sliding engagement with the interior wall of the casing **16** to hold the apparatus **20** centered in the casing **16**. Similarly, vertically extending, lower bow springs **34**, also forming part of the centralizer assembly **27**, are arranged on a 120° spacing in sliding engagement with the inner wall of the casing **16** to aid in holding the apparatus **20** centered in the casing **16**.

As clearly illustrated in FIGURE 1, a pair of vibrators **40** and **42** are suitably mounted in the tubular body **22**. The vibrator **40** is arranged so that its axis extends generally transversely to the longitudinal axis of the tubular body **22** while the vibrator **42** has its axis extending generally parallel to the longitudinal axis of the tubular body **22**. It will be understood that the vibrator **40** is connected with a source of electrical energy (not shown) through the conductors **44** and the cable **28**. Similarly, the vibrator **42** is connected with the source of electrical energy (not shown) through the conductors **46** and the cable **28**.

A power supply **48** is located in the tubular body **22**. The power supply **48** is connected by conductors **50** and the cable **28** with the source of electrical energy (not shown). The power supply **48** includes the necessary capacitors, inductances, resistances and other electrical apparatus required to energize the lamp **52** and is connected thereto by conductors **53**.

The lamp **52** may be of any suitable configuration, the principal criteria being its ability to transmit extremely high intensity light energy to a crystal **54**. While the lamp **52** illustrated is the preferred form, that is, in the form of a helix encircling the crystal **54**, a cluster of elongated lamps extending parallel to the crystal **54** or a single lamp disposed parallel to the crystal **54** have been successfully utilized when proper reflecting members are provided.

Various types of lamps are currently commercially available that will provide either a flash, that is, a substantially instantaneous output of relatively high magnitude or a high intensity, continuously burning lamp. One flash lamp in fairly common use is filled with xenon gas and provides a brilliant blue-green flash of visible light for irradiating the crystal **54**.

The circuitry of the power supply **48** and the lamp **52** are not shown since the precise circuit used will vary depending upon the power requirements and the type of lamp **52** utilized. However, a typical electric circuit for the power supply **48** and lamp **52** is illustrated at p. 158 in "This Story of the Laser" written by John M. Carroll and published by E. P. Dutton & Company, Inc. of New York.

As illustrated in FIGURE 1, the crystal **54** is disposed transversely with respect to the longitudinal axis of the tubular body **22**. A reflecting end **56** of the crystal **54** is located in an aligning member **58** positioned in the wall of the tubular body **22**. A discharge end **60** on the crystal **54** extends through a partially threaded aperture **62** formed in a protuberance **63** on the tubular body **22**. The discharge end **60** is also reflective, but less reflective than the reflecting end **56** for reasons that will become more apparent as the description proceeds.

An O-ring seal **64** is disposed in the tubular body **22** encircling the discharge end **60** of the crystal **54**. The O-ring seal **64** and the aligning member **58** are preferably constructed from materials that will withstand the heat generated in the crystal **54** during its operation.

The crystal **54** may be suitably constructed from an elongated cylindrical rod of ruby. The discharge end and the reflecting end are ground optically flat, transparent and essentially parallel. As previously mentioned, a reflective material is provided on each end of the crystal **54** with a less dense reflecting material being located on the discharge end **60**. Many other crystals have also been found to be satisfactory, for example, the crystal could be calcium tungstate doped with the rare-earth neodymium or any of several other crystals containing rare-earth or actinide metals.

Manifestly, the use of the crystal **54** generally relates to the so-called "lasers," that is, to electromagnetic energy systems involving light amplification by stimulated emission of radiation. It should be understood that the invention also contemplates the use of an electromagnetic system commonly known as a "maser," that is, microwave amplification by stimulated emission of radiation. There is some disagreement among scientists as to the exact term that should be applied to such systems and therefore, the generic term "quantum device" has been utilized for such electromagnetic systems.

Referring again to FIGURE 1, shown therein is a convex lens **66** mounted in the aperture **62** adjacent the discharge end **60** of the crystal **54**. The lens **66** is provided to concentrate the electromagnetic energy beam discharged by the crystal 54. A threaded retainer ring 68 is disposed in threaded engagement in the aperture 62 to retain the lens 66 therein. A substantially transparent fluid 70, such as silicone grease, is disposed in the aperture 62 to inhibit the entrance of well fluids into the aperture 62 adjacent the lens 66.

As shown in FIGURE 1 and more clearly in FIGURE 2, the perforating apparatus 20 is provided with a pair of reflecting members 72 and 74 that have reflective, concave inner surfaces partially encircling the lamp 52 and the crystal 54. A mounting lug 76 extends upwardly from reflective member 72 and is suitably connected to the lower end of the power supply 48. Similarly, a mounting lug 78 extends downwardly from the reflective member 74 and is suitably connected with the upper end of the plug 30. The reflective members 72 and 74 are provided to gather light energy emitted by the lamp 52 in a direction away from the crystal 54 and to reflect such light energy into the crystal 54, thereby increasing the efficiency of the system.

In addition to the various materials from which the crystal 54 may be constructed, the crystal 54 may also be arranged in various configurations as illustrated by FIGURES 3, 4 and 5. FIGURE 3 illustrates an elongaed crystal 154 having an optically flat end coated with a reflecting material 156. The opposite or discharge end of the crystal 154 is also optically flat and coated with a reflecting material 158. It will be understood that the reflecting material 158 is less dense than the reflecting material 156 so that the electromagnetic energy generated in the crystal 154 will be discharged therethrough.

Connected with the crystal 154 adjacent the reflecting material 158 is a lens 160. The lens 160 is optically flat adjacent the reflecting material 158 and is convex on the other surface thereof whereby the electromagnetic energy emitted by the crystal 154 will be concentrated as previously described in connection with the lens 66.

As previously mentioned, the crystals utilized in the perforating apparatus 20 may become quite hot during their operation. Therefore, the embodiment of crystal illustrated in FIGURE 4 and indicated by the reference character 254 provides a means for relieving some of the heat from the crystal. As shown therein, the crystal 254 also includes the reflecting and discharge ends which are coated with the reflecting materials 156 and 158, respectively. Extending through the crystal 254 is an opening 256 as is most clearly shown in FIGURE 4A. If desired, the wall of the opening 256 may be coated with a reflective material to inhibit the loss of light energy therethrough. It should also be pointed out that while only one opening 256 is illustrated, a plurality of axially extending openings may be formed in the crystal 254 if desired.

FIGURES 5 and 5A illustrate the construction of still another embodiment of crystal, designated by the reference character 354, that functions to remove heat therefrom. As most clearly illustrated in FIGURE 5, the crystal 354 also includes reflective materials 156 and 158 coating the reflecting and discharge ends, respectively. A plurality of thermally conductive members 356 are embedded in the crystal 354 generally parallel to the longitudinal axis thereof. The members 356 extend from the reflecting end of the crystal 354 and are connected with the plug or heat sink 30. FIGURE 5A illustrates one arrangement of the thermally conductive members 356 in the crystal 354.

OPERATION

When it is desired to perforate the formation 12 surrounding the well bore 10, the perforating apparatus 20 is connected by the cable 28 with appropriate hoisting apparatus (not shown) and with a source of electrical energy (not shown). The perforating apparatus 20 is then lowered through the casing 16 until the aperture 62 is disposed adjacent the formation 12 to be perforated.

The bow springs 32 and 36 are in sliding engagement with the interior wall of the casing 16 to center the apparatus 20 therein and to prevent the application of torque to the cable 28 when the motor 26 is rotating the body 22. Also, the protuberance 63 is engaging or very close to the casing 16 so that the discharge end 60 of the crystal 54 is disposed at a predetermined distance from the casing 16 and formation 12. Maintaining the protuberance 38 very close to the casing 16 also aids in preventing the entrance of well fluids into the space between the crystal 54 and the interior wall of the casing 16.

When the perforating apparatus 20 reaches the desired position in the well bore 10, the movement thereof is arrested and the perforating apparatus 20 is suspended in the casing 16. Appropriate switches (not shown) are actuated to energize the vibrators 40 and 42 to impart vibration to the perforating apparatus 20. Also, appropriate switches (not shown) are actuated to permit the flow of electrical energy into the power supply 48 and motor 26 (when desired).

Due to the large amount of energy required to actuate the crystal 54, the power supply 48 requires a period of time to fully charge the capacitors (not shown) that are normally contained therein. After the power supply 48 has been fully charged, a triggering mechanism (not shown) is actuated to deliver, almost instantaneously, energy from the power supply 48 to the lamp 52.

When energized, the lamp 52 emits light energy of relatively high intensity to irradiate the crystal 54. As previously mentioned, and as will be obvious from viewing FIGURE 1, a portion of the light emitted by the lamp 52 is oriented in a direction relatively away from the crystal 54. This portion of the light energy engages the reflective members 72 and 74 and is reflected thereby toward the crystal 54, thus increasing the efficiency of the light system.

There are many treatises available describing the theoretical operation of laser crystals, such as the crystal 54, and therefore, such theory will not be described herein. However, and very generally, the photons given off in the irradiated crystal 54 are reflected along the longitudinal axis thereof between the reflecting end 56 and the discharge end 60 until sufficient energy develops therein for the photons to burst through the less reflective discharge end 60 of the crystal 54.

The energy emitted by the crystal 54 has been found to be of extremely high intensity, to be coherent and monochromatic. The emitted energy beam then passes through the lens 66, which may be omitted if desired, wherein the emitted beam is concentrated.

After passing through the lens 66, the beam engages and disintegrates the portion of the casing 16 engaged thereby. Also, the electromagnetic energy beam perforates the cementitious material 18 as well as extending for some distance into the formation 12.

As is well known to those skilled in the art of quantum devices, the emitted beam is of relatively small diameter and the perforation 14 is, therefore, correspondingly small. However, and as previously mentioned, the vibrators 40 and 42 maintain the perforating apparatus 20 in constant vibratory movement so that the emitted beam is moved over a larger surface area of the casing 16 than the diameter of the beam whereby a relatively larger passageway 14 is formed.

It should be pointed out that although relatively large flow passageways or perforations are desirable in some instances in formations, the smaller the passageway formed in unconsolidated sand formations, the less quantity of undesirable sand that will be produced therethrough. However, it must be remembered that the perforations 14 should be sufficiently large so that flow will occur therethrough, but small enough to exclude or inhibit the flow of sand.

The motor 26, when energized, rotates the body 22 into any desired position. Combining vertical movement of the apparatus **20** by means of the cable **28** and the rotational movement provided by the motor **26** permits the formation of virtually any desired configuration of perforations. Thus a relatively small area of the formation **12** can be saturated with the perforations **14** whereby a flow area, at least equal to the available area formed when utilizing bullets or jet charges, can be provided if desired.

Furthermore, the perforating apparatus **20** can be discharged to form as many perforations as desired without damage to or destruction of the perforating apparatus. In fact, and as previously mentioned, a sufficient number of perforations can be made to form, in situ, a foraminous well screen that has excellent sand control characteristics. The apparatus **20** is completely retrievable and no "junk" will be left in the well which might interfere with subsequent completion or drilling procedures.

It will be understood that the perforating apparatus **20** described in detail hereinbefore is presented by way of example only and that many changes and modifications can be made thereto without departing from the spirit of the invention or from the scope of the annexed claims.

What I claim is:

1. Perforating apparatus for use in a well bore or the like comprising:
- a quantum device movable in the well bore and including
  - power supply means, and
  - an energy emission portion operably associated with said power supply means, said emission portion being oriented generally towards a portion of the wall surrounding the well bore and arranged, when energized by said power supply means, to emit a beam of coherent, monochromatic electromagnetic energy of sufficient intensity to disintegrate the portion of the wall engaged thereby, whereby a perforation is formed therein intersecting the well bore; and
- means connected with said quantum device for moving said device along the well bore.

2. The perforating apparatus of claim 1 wherein said energy emission portion includes an elongated, generally cylindrical crystal having a reflecting end and a reflective discharge end, said discharge end being less reflective than said reflecting end.

3. The perforating apparatus of claim **2** wherein said power supply means includes light emitting means located adjacent said crystal, whereby said light energy is transmitted to said crystal when said power supply means is energized.

4. The perforating apparatus of claim **2** wherein said energy emission portion also includes lens means located between said discharge end and the wall of the well bore for concentrating the emitted energy beam, thereby increasing the energy density engaging the wall of the well bore.

5. The perforating apparatus of claim **4** wherein said lens means is connected to the discharge end of said crystal.

6. The perforating apparatus of claim **2** wherein said crystal has at least one passageway extending therethrough intersecting the discharge and reflecting ends of said crystal.

7. The perforating apparatus of claim **6** wherein the wall of each said passageway is light reflective.

8. The perforating apparatus of claim **2** wherein said crystal includes a plurality of conductive members extending therethrough for conducting heat away from said crystal.

9. The perforating apparatus of claim **1** and also including a hollow body member containing said quantum device, said body member being movable in the well bore and having an aperture extending through a wall thereof adjacent the wall of the well bore when said body member is disposed therein, and said energy emission portion being oriented in said body member to emit said beam through said aperture.

10. The perforating apparatus of claim **9** wherein
- said energy emission portion includes an elongated, generally cylindrical crystal having a reflective discharge end aligned with said aperture and a reflecting end, said discharge end being less reflective than said reflecting end;
- said power supply means includes light emitting means located adjacent said crystal, whereby light energy is transmitted to said crystal when said power supply means is energized; and
- said apparatus also includes reflecting means located in said hollow body member and arranged to reflect a portion of the light from said light emitting means into said crystal.

11. The perforating apparatus of claim **10** and also including:
- a heat sink constructed from a thermally conductive material connected with said hollow body member; and
- a plurality of conductive members extending through said crystal and having at least one end of each of said conductive members connected with said heat sink.

12. The perforating apparatus of claim **10** and also including vibration means located in said body member for imparting vibrations to said crystal.

13. Perforating apparatus for use in a cased well bore or the like comprising:
- a tubular body member movable in the casing and having an aperture extending through the wall thereof adjacent the casing when said body member is disposed therein;
- a motor operably connected with said body member for rotating said body member in said well bore;
- cable means extending into said casing for moving said apparatus in the casing;
- centralizer means arranged to slidingly engage the casing and connected with said motor and cable means for centering said apparatus in the casing;
- an adapter connected with and closing one end of said body member and engaging said cable means, whereby said body member is operably connected with said cable means;
- a heat sink constructed from a thermally conductive material connected with and closing the other end of said body member forming a chamber therein;
- a source of electrical energy located remote from said body member;
- a power supply located in said chamber and electrically interconnected with said source of electrical energy;
- an elongated, generally cylindrical crystal disposed in said chamber and including a reflective discharge end aligned with said aperture and a reflecting end, said discharge end being less reflective than said reflecting end;
- light emitting means in said chamber adjacent said crystal operably connected with said power supply, whereby said crystal emits a beam of coherent, monochromatic electromagnetic energy from the discharge end thereof of sufficient intensity to disintegrate the portion of the casing and wall of the well bore engaged thereby when said power supply is energized;
- reflecting means located in said chamber for reflecting a portion of the light emitted by said light emitting means into said crystal; and
- seal means located in said aperture for preventing the entrance of well fluids into said chamber.

14. A method of completing a well in an unconsolidated formation including the steps of:

positioning a well casing in the well adjacent said formation;

depositing cementitious material in the annular space between said casing and said formation;

positioning a quantum device including an energy beam emission portion in said casing adjacent said formation;

energizing said emission portion, whereby an energy beam emitted thereby perforates said casing, cementitious material, and formation; and

repeating the two last mentioned steps forming a plurality of spaced perforations.

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DAVID H. BROWN, Primary Examiner

U.S. Cl. X.R.

175—16; 331—94.5