

Aug. 19, 1969

A. A. VENGHIATTIS

3,461,964

WELL PERFORATING APPARATUS AND METHOD

Filed Sept. 9, 1966

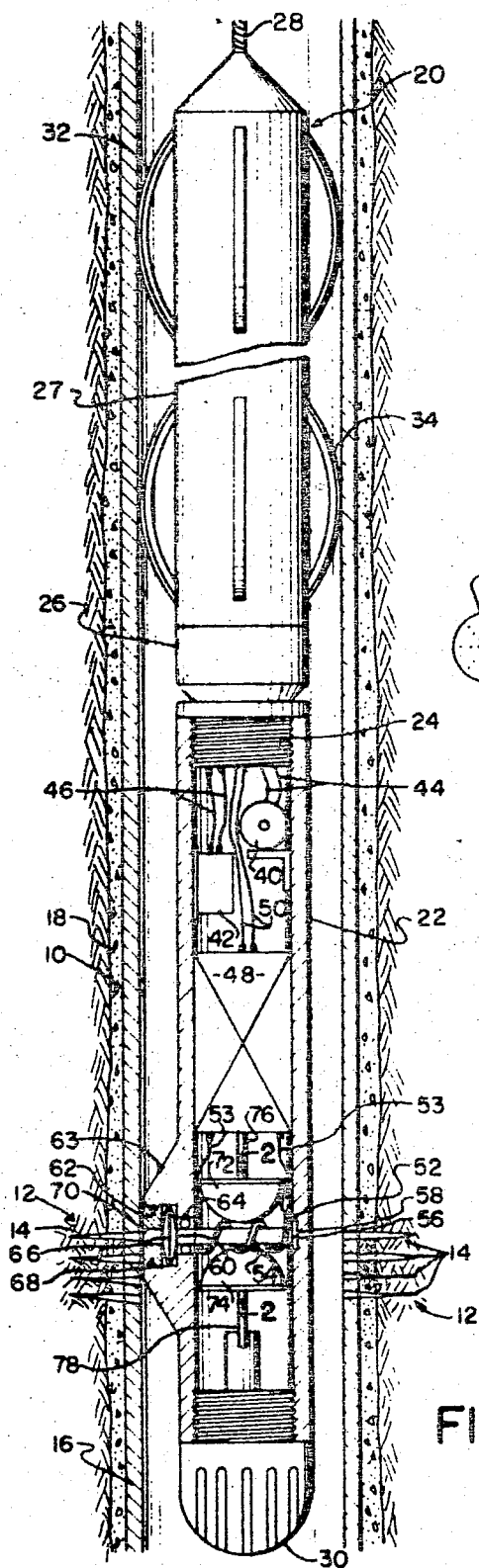


FIG. 1

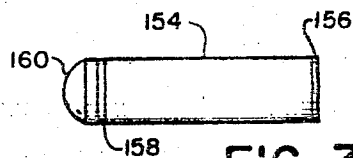


FIG. 3

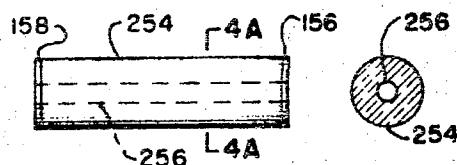


FIG. 4

FIG. 4A

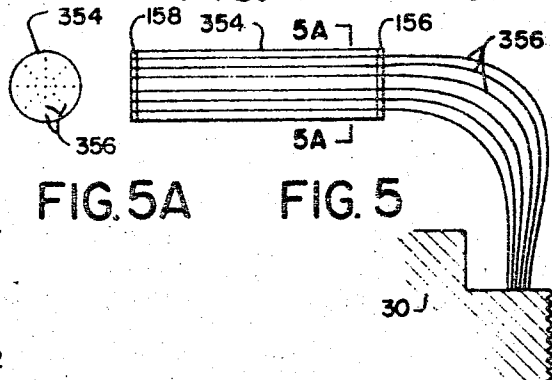


FIG. 5A

FIG. 5

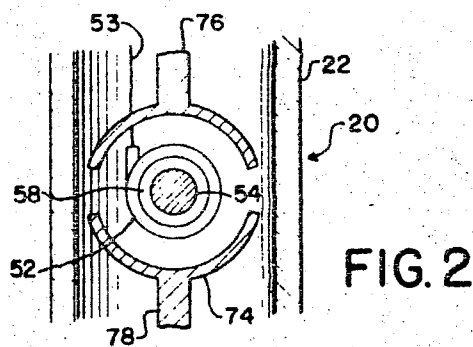


FIG. 2

INVENTOR,

ALEXIS A. VENGHIATTIS

BY

Ray L. V. Thibault

ATTORNEY

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3,461,964

WELL PERFORATING APPARATUS AND METHOD
 Alexis A. Venghiattis, Weston, Conn., assignor to
 Dresser Industries, Inc., Dallas, Tex., a corpora-
 tion of Delaware

Filed Sept. 9, 1966, Ser. No. 578,304

Int. Cl. E21b 43/11

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 where-
 in 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 de-
 vice that is movable in the well bore that can be dis-
 charged 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 an-
 other 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 pro-
 duced 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 produc-
 tive 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 perfora-
 tions. 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 uncon-
 solidated sand, the perforations are usually so large as
 compared to the grain size of the sand to permit migra-
 tion of the sand with well fluids into the interior of the
 casing. Manifestly, if a sufficient quantity of sand enters

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the casing, serious damage or destruction of equipment
 operating in the casing may result. Therefore, special
 equipment and methods are generally utilized when un-
 consolidated 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 gen-
 erally perforated at such other zones by conventional
 means and, if the formation is unconsolidated, the pre-
 viously 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 condi-
 tions 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 per-
 forating 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 emis-
 sion 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 elec-
 tromagnetic 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 perforat-
 ing 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 im-
 proved perforating apparatus that is completely retriev-
 able.

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 surround-
 ing 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 follow-
 ing 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 and 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 pro-

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vided 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 elongated 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

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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 there-through. 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 mem-

ber 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 slidably 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