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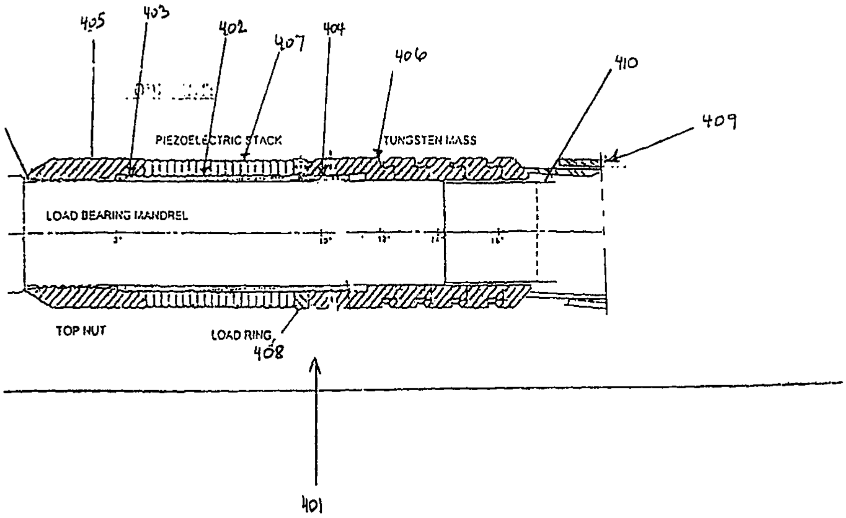
(54) Title: SINGLE POINT CONTACT ACOUSTIC TRANSMITTER



(57) Abstract

The invention is an acoustic transmitter (301, 401) that imparts vibratory stresses onto a signal propagation medium such as oil well tubing when actuated by an electric driver. In one embodiment, the acoustic transmitter (301, 401) utilizes a mechanical driver that includes piezoelectric elements (304) to generate the vibratory stresses. The acoustic transmitter (301, 401) is mechanically attached at only one point to the signal propagation medium. This single point attachment eliminates loading on the acoustic transmitter (301, 401) from compressive and tensile forces carried by the signal propagation medium. A mass (406) backing the mechanical driver may be used to extend the frequency range over which the acoustic transmitter (301, 401) is operable. In addition, the resonance response of the acoustic transmitter (301, 401) may be minimized by the use of a viscous dampener (409). The viscous dampener (409) is configured to "couple" with the mechanical driver when the acoustic transmitter is operating and to "uncouple" with the mechanical driver at other times.

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SINGLE POINT CONTACT ACOUSTIC TRANSMITTER

CROSS-REFERENCE TO RELATED APPLICATIONS

Not Applicable.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

Not Applicable.

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates generally to devices that transmit acoustic or stress wave signals. More particularly, the present invention relates to devices that transmit acoustic or stress signals through an elastic media. Still more particularly, the present invention relates to acoustic transmitters that transmit acoustic or stress signals via well tubing.

Description of the Related Art

The recovery of subterranean hydrocarbons, such as oil and gas, usually requires drilling boreholes thousands of feet deep. In addition to an oil rig on the surface, production tubing extends downward through the borehole to hydrocarbon formation. The tubing may have horizontal, or lateral bores which incorporate valves to control the flow of hydrocarbons or other well fluids. To efficiently operate this complex production system, well site personnel often require reliable "real time" data regarding borehole conditions. For example, knowing downhole pressure and temperature is vital in determining whether production is proceeding within permissible operating parameters. With the prevalence of multi-lateral drilling, characterizing the well fluids, using data such as resistivity measurements, plays an important role in deciding which valves to actuate in order to maximize hydrocarbon recovery. Because accurate well bore data is essential to effective management of well site operations, reliable means is required to transmit accurate borehole environment information to the surface.

Several approaches have been employed with limited success to transmit downhole telemetry data to the surface. Linking downhole instrumentation to the surface with wiring has proven exceedingly expensive and unreliable due to the corrosive fluids and high ambient temperatures often found in the well. Electromagnetic radiation has been utilized as a transmission media. However, the non-uniformity in conductivity has prevented wide spread use of this approach. More common is the practice of transmitting data using pressure waves in drilling fluids such as drilling mud, or mud pulse / mud siren telemetry. However, the low baud rate normally produced by mud pulse telemetry transmitters limits the ability of well site personnel to analyze and respond to well conditions. Further, this approach is not available for production tubing because no drilling fluids are present.

Telemetry utilizing acoustic transmitters in the pipe string, such as a mandrel or production tubing, has emerged as a potential method to increase the speed and reliability of data transmission from downhole to the surface. When actuated by a signal such as a voltage potential from a sensor, an acoustic transmitter mechanically mounted on the tubing imparts a stress wave or acoustic pulse onto the tubing string. Because metal pipe propagates stress waves more effectively than drilling fluids, acoustic transmitters used in this configuration have been shown to transmit data in excess of 10 BPS (bits per second). Furthermore, such acoustic transmitters can be used during all aspects of well site development regardless of whether drilling fluids are present.

Despite the promise of acoustic transmitters as an approach to increase data transmission rates, tubing string within the borehole often develops mechanical stresses that can render prior art acoustic transmitters inoperative. Referring to Figure 1, a prior art transmitter **101** is disposed downhole. Prior art transmitter **101** includes a piezoelectric stack **102** having a plurality of elements and a member **103** having a first end **104** and a second end **105**. The first end **104** and second end **105** of the member **103** are solidly connected to production tubing **106**. Member **103** has an annular recess **107** that captures the piezoelectric stack **102**. A substantially axial interference fit exists between the piezoelectric stack **102** and the recess **107** in order to induce an axial loading that tends to compress the elements of the piezoelectric stack **102** together; i.e., the piezoelectric stack **102** is under a compressive loading as indicated by arrows **108**.

As a voltage differential is applied to the piezoelectric stack **102**, the elements of the piezoelectric stack **102** expand axially in the recess **107**. The piezoelectric stack then contracts when the voltage across it returns to zero. As long as the piezoelectric stack **102** is compressed within the recess **107**, piezoelectric stack **102** expansion will axially displace the first end **104** of the member **103** with respect to the second end **105** of the member **103** and thereby induce a controlled stress onto the tubing **106**. This controlled stress generates waves in the tubing that are propagated to the surface. As such, by applying voltage differentials to piezoelectric stack **102** in a controlled manner, waveforms are generated that transmit data to the surface.

For the acoustic transmitter to function properly, the recess **107** must maintain the compressive loading **108** of the piezoelectric stack **4** within a limited range. If stresses in the tubing **106** push the first end **104** and second end **105** of the member **103** toward one another, the resulting compressive loading may be too severe and result in a "locking up" of the piezoelectric stack **102** by preventing the piezoelectric stack **102** from expanding as voltage is applied. On the other hand, if stresses in the tubing **106** pull ends **104**, **105** apart, tensile loading **109** results. This tensile loading **109** reduces the compressive loading **108** of the piezoelectric stack **102**. When tensile loading **109** is sufficiently high, the elements of the piezoelectric stack **102** separate and are no longer able to generate stress signals on tubing **106**.

Unfortunately, compressive and tensile loading are often encountered during normal hydrocarbon drilling and production. Referring to Figure 2A, a tubing **201a** having an acoustic transmitter **204a** is suspended within a borehole **202a** from a rig **203a.** Where tubing **201a** extends for several thousand feet, a prior art transmitter **204a** interposed in that span can be subjected to significant tensile loading, T. Referring now to Figure 2B, if a packer **205b** were released in the middle of such a long expanse of tubing, a prior art transmitter **206b** located above the packer **205b** may encounter compressive loading, C. Moreover, as shown in Figure 2C, wells that have deviated tubing **207c** present unique problems because it is impossible to predict which sections of tubing **207c** will be subjected to compressive loading and which sections of tubing **207c** will be subjected to tensile loading. Therefore, even under normal operating conditions, prior art transmitters can suffer from complete signal loss because of piezoelectric stack "lock up" or separation.

Additionally, when prior art acoustic transmitters are operated at well sites, undesirable multiple resonances are often displayed during band sweeps. That is, transmissions over particular frequencies generate amplitude spikes that complicate the monitoring of well bore data. Moreover, the locations of the resonance frequencies vary with the unique configuration of each well site.

These and other problems have prevented the oil and gas industry from utilizing fully acoustic transmitters. As such, there exists a need for an improved acoustic transmitter. The present invention overcomes the deficiencies of the prior art.

SUMMARY OF THE INVENTION

The present invention includes a single mechanical connection to the tubing. Threaded into the tubing is a top nut. Connected to the top nut is a support sleeve around which a piezoelectric stack is held. Capturing and compressing the piezoelectric stack is an assembly consisting of a load ring, tungsten mass and viscous damper.

The present invention comprises a combination of features and advantages which enable it to overcome the various problems of the prior art. The various characteristics described above, as well as other features, will be readily apparent to those skilled in the art upon reading the following detailed description of the preferred embodiments of the invention, and by referring to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more detailed description of the preferred embodiment of the present invention, reference will now be made to the accompanying drawings, wherein:

Figure 1 is a cross-sectional view of a prior art acoustic transmitter.

Figure 2A is a cross-sectional elevation view of a typical well site.

Figure 2B is a cross-sectional view of a prior art transmitter disposed above a packer on a tubing string.

Figure 2C is a cross-sectional view of a prior art transmitter disposed in a deviated borehole.

Figure 3 is a cross-sectional view of the acoustic transmitter of the present invention.

Figure 4 is a cross-sectional view of another embodiment of the acoustic transmitter of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to Figure 3, there is shown the acoustic transmitter **301** mounted onto a tubing **302** at a single point or end. In lieu of tubing, drill pipe or other appropriate tubular member may be used. The acoustic transmitter **301** includes a lower jam nut **303**, a piezoelectric stack or mechanical driver **304** having a plurality of elements **304a**, a load washer **305**, and a plurality of connectors such as bolts **306**. The piezoelectric stack **304** has axial clearance holes **307**. Bolts **306** extend through the clearance holes **307** and couple with mating threads **308** on the lower jam nut **303**. This coupling provides a desired compressive force to piezoelectric stack **304**. Lower jam nut **303** is mechanically secured to the tubing **302**. Because the piezoelectric stack **304** can fracture when subjected to concentrated forces, the load washer **305** is interposed between the heads **309** of bolts **306** and piezoelectric stack **304** to distribute the compressive forces evenly over the elements making up piezoelectric stack **304**.

Referring still to Figure 3, the acoustic transmitter **301** connects to tubing **302** only at the lower jam nut **303**, i.e. at a single point. By avoiding two points of contact on opposing sides of the piezoelectric stack **304**, compressive or tensile loading on the tubing **302** cannot push together or pull apart the piezoelectric stack **304**. Consequently, the compressive and tensile forces that may develop in the tubing **302** cannot be transferred to the piezoelectric stack **304**. As such, the desired compressive force imparted by bolts **306** and load washer **305** remains relatively constant and keeps piezoelectric stack **304** in an operable range. Thus, prior difficulties with stack separation or stack "lock up" are eliminated.

Alternatives to using a piezoelectric stack **304** as a driver to generate acoustic signals include magneto-strictive devices such as Terfenol. Terfenol, as the driving mechanism, imparts a controlled stress to the tubing. It may also, in certain situations, provide a larger amplitude signal. Thus, the mechanical driver can be selected to optimize the response of the acoustic transmitter. As used herein, the term "driver" includes elements capable of imparting a vibratory stress onto a propagation medium.

The acoustic transmitter **301** of Figure 3 is expected to provide satisfactory high frequency signals above about 1800 Hz for transmission upstream of the borehole. However, well applications often require lower frequency signals to be transmitted upstream. For example, the interfaces or connections between sections of tubing may block high frequency signals, but allow low frequency signals to pass. Therefore, the acoustic transmitter **301** of the present invention is advantageous in that it can generate a low frequency signal which is preferred. The preferred acoustic transmitter **301** of the present invention improves performance so that the acoustic transmitter **301** may provide satisfactory signals at frequencies below 1800 hz.

Referring now to Figure 4, there is shown an alternative embodiment of the preferred acoustic transmitter. Acoustic transmitter **401** includes a housing (not shown), a support sleeve **402** having a mounting end **403** and a free end **404**, a top nut **405**, a backing mass **406** having internal threads, a piezoelectric stack **407** having a plurality of elements, a load ring **408** between backing mass **406** and piezoelectric stack **407**, and a viscous dampener **409**. Also shown is tubing **410**.

Top nut **405** establishes a fixed mechanical connection to the tubing **410**. This mechanical connection may be mating threads, as shown, or some other appropriate attachment. Mounting end **403** of the support sleeve **402** rigidly affixes to top nut **405**. The preferred acoustic transmitter **401** uses a suitable glue as the affixing method, but any suitable affixing mechanism may be employed. Piezoelectric stack **407** surrounds the support sleeve **402** and abuts against the top nut **405** and load ring **408**. The free end **404** of support sleeve **402** has threads that mate with the internal threads of the backing mass **406**. The backing mass **406** couples with the free end **404** of the support sleeve **402** and thereby captures the piezoelectric stack **407**. The load ring **408** interposed between the backing mass **406** and the piezoelectric stack **407**.

Still referring to Figure 4, the preferred acoustic transmitter **401** clamps the piezoelectric stack **407** between the top nut **405** and the backing mass **406**. As the backing mass **406** is threaded onto the support sleeve **402**, the backing mass **406** travels axially toward the top nut **405**. Incremental axial movement of backing mass **405** will gradually clamp the load ring **408** and piezoelectric stack **407** against the top nut **405**. When the backing mass has traveled a sufficient distance to induce proper compressive loading in the piezoelectric stack **407**, set screws (not shown) lock the backing mass **406** in place. A compressive stress of 2500-7000 psi (pounds per square inch) applied to the piezoelectric stack **407** appears to generate suitable signals in well bore applications. If a mechanical driver other than piezoelectric elements **406** is used, the configuration of the preferred acoustic transmitter **401** should be revised accordingly. As used herein, the term “clamp” includes any appropriate structure that captures the piezoelectric stack **407** and applies to it a desired compressive loading.

During operation, the preferred acoustic transmitter **401** receives input from an electric driver or sensor (not shown). The piezoelectric stack **407** reacts to the input, such as a voltage differential, by expanding. Because the piezoelectric stack **407** is compressed against a dense and relatively immovable Tungsten mass **406**, the piezoelectric stack **407** expansion is transferred as a compressive stress to the tubing **410** via the top nut **405**. Thus, as an electric driver provides an excitation signal, the acoustic transmitter **401** “fires” and sends an acoustic pulse through the tubing **410** to the surface.

Backing mass **406**, located at the free end of piezoelectric stack **407**, improves operation of the preferred acoustic transmitter at lower frequencies. Backing mass **406** acts as an inertial element against which the piezoelectric stack **407** can react or "push." This additional mass allows the piezoelectric stack to vibrate at lower frequencies. Tungsten is preferable as the backing mass **406** material because its high mass density allows a compact configuration. If space considerations are not relevant, lower density materials can alternately be employed. Indeed, a piezoelectric stack **407** of sufficient mass could provide an inherent and sufficient backing mass.

A related beneficial aspect of the backing mass **406** is that the weight of the backing mass **406** has a predicable effect on the operating frequency of the preferred acoustic transmitter **401**. Thus, well site personnel can "fine tune" the response characteristics of the preferred acoustic transmitter **401** by varying the weight of the backing mass **406**.

Acoustic transmitter **401** uses a support sleeve **402** for two reasons. First, as shown in Figure 3, it is expected that the bolt clearance holes **307** in the piezoelectric stack **304** will cause the acoustic transmitter **301** to occasionally generate nonsymmetrical stress waves. Second, clearance holes **307** weaken the structural integrity of the piezoelectric stack **304**. Referring back to Figure 4, these problems are largely alleviated by using a support sleeve **402** that requires only one concentric clearance hole in the piezoelectric stack **407**. A Teflon coating (not shown) is applied to the support sleeve **402** surfaces that contact the piezoelectric stack **407** to preserve free axial movement of the piezoelectric stack **407** along the support sleeve **402**.

Referring now to Figure 4, the preferred transmitter **401** uses Invar as the support sleeve **402** material. Invar has a very low coefficient of thermal expansion, similar to the coefficient of thermal expansion for the piezoelectric stack **407**. Consequently, the piezoelectric stack **407** and support sleeve **402** will expand at the same rate as borehole temperatures increase. Therefore, the possibility that the piezoelectric stack **407** may lose compression and cause the elements of the piezoelectric stack **407** to separate at elevated ambient temperatures in the borehole is minimized. If Invar is not used as the material, a set of springs (not shown) can be installed between the piezoelectric stack **407** and load ring **408** to take up the slack caused by the thermal expansion of the support sleeve **402**.

Viscous dampener **409** is solidly mounted to the tubing **410** and variably coupled to the backing mass **406**. The inclusion of viscous dampener **409** is not necessary for adequate operation of the preferred acoustic transmitter. However, viscous dampener **409** minimizes the resonance responses of preferred acoustic transmitter **401** without transferring compressive or tensile stresses to the piezoelectric stack **407**. As discussed earlier, transmissions through piping often are complicated by occurrences of resonance frequencies. As such, a viscous dampener as taught in U.S. Patent No. 5,510,582, the teachings of which are here incorporated by reference, is preferably used as part of this preferred acoustic transmitter. During the fast movement or oscillations associated with acoustic wave or pulse transmissions, a properly adjusted viscous dampener **409** "solidly" couples the piezoelectric stack **407** and backing mass **406** to the tubing **410**. This solid coupling inhibits the sharp "spikes" in amplitude.

However, when the tubing **410** encounters tensile and compressive loadings under normal operating conditions, these loadings occur through slow movement of the tubing **410**. A properly adjusted viscous dampener **409** "uncouples" with the piezoelectric stack **407** from the tubing **410** under such conditions and does not transfer the tensile or compressive loading to the piezoelectric stack **407**.

Multiple acoustic transmitters can be arrayed along the tubing string to reinforce signal transmission. In order to prevent interference, the electrical timing of all acoustic transmitters employed must be coordinated to ensure sequential firing.

The term "piezoelectric stack" or "piezoelectric elements" is used throughout to identify an element or combination of elements that exhibit the "piezoelectric effect."

While preferred embodiments of this invention have been shown and described, modifications thereof can be made by one skilled in the art without departing from the spirit or teaching of this invention. The embodiments described herein are exemplary only and are not limiting. Many variations and modifications of the system and apparatus are possible and are within the scope of the invention. Accordingly, the scope of protection is not limited to the embodiments described herein, but is only limited by the claims which follow, the scope of which shall include all equivalents of the subject matter of the claims.

CLAIMS

WHAT IS CLAIMED IS:

1. An apparatus to transmit acoustic signals through an signal propagation medium, comprising:

a driver capable of expansion and contraction, wherein said expansion and contraction generates vibratory stresses; and

a clamp associated with said driver and having a first portion and a second portion, said first portion of said clamp suitable to connect to said signal propagation medium, wherein said first portion of said clamp is also suitable as a conduit for said driver to deliver vibratory stresses to said signal propagation medium, said second portion of said clamp being free from connection with said signal propagation medium, and wherein said first portion and said second portion cooperate to provide a compressive force to said driver.

2. The apparatus of claim 1, further comprising a viscous dampener variably coupled with said second portion of said clamp, said viscous dampener coupling with said driver when said driver generates said vibratory stresses and uncoupling with said driver when driver does not generate said vibratory stresses.

3. The apparatus of claim 1, wherein said clamp further comprises a mass portion, said mass portion associated with said driver and providing said driver with an inertial mass against which to expand and contract.

4. The apparatus of claim 3, wherein said second portion is an end of said clamp and further wherein said mass portion attaches to said second portion.

5. The apparatus of claim 3, further comprising:

a viscous dampener, said viscous dampener being connected to said mass portion.

6. The apparatus of claim 1, further comprising:

a bolt, said bolt connecting said second portion of said clamp to said first portion of said clamp.

7. The apparatus of claim 1, further comprising:

a sleeve, said sleeve connecting said second portion of said clamp to said first portion of said clamp.

8. The apparatus of claim 1, wherein said signal propagation medium is tubing suitable for use in a borehole.

9. The apparatus of claim 1, wherein said signal propagation medium has an outer surface, and wherein said first portion of said clamp is configured to attach to said outer surface of said signal propagation medium.

10. The apparatus of claim 1, wherein said driver is a set of piezoelectric elements.

11. A method of transmitting acoustic signals in a signal propagation medium, comprising the steps of:

(a) connecting a driver to said signal propagation medium to form a single connection only between said driver and said signal propagation medium;

(b) activating said driver.

12. The method of claim 11, wherein said connecting step includes attaching an inertial mass to said mechanical driver.

13. The method of claim 12 wherein said connecting step includes coupling a viscous dampener to said mechanical driver.

14. The method of claim 12, wherein said driver is piezoelectric.

15. An apparatus for transmitting acoustic signals through a signal propagation medium, comprising:

a means for imparting vibratory stresses into said signal propagation medium;

a means for mounting said means for imparting vibratory stresses onto said signal propagation medium;

a mass attached to said means for imparting vibratory stress; and

a means for viscously dampening said means for imparting vibratory stresses.

16. An apparatus for transmitting acoustic signals through a signal propagation medium, comprising:

a clamp having a first end, said first end suitable for connection to said signal propagation medium, accomplishing connection by cantilevering said clamp from said signal propagation medium; and

a driver housed within said clamp and juxtaposed to said first end of clamp, said driver capable of expansion and contraction, said expansion and contraction imparting vibratory stresses through said first end of clamp onto said signal propagation medium, and wherein said clamp provides a compressive force to said driver.

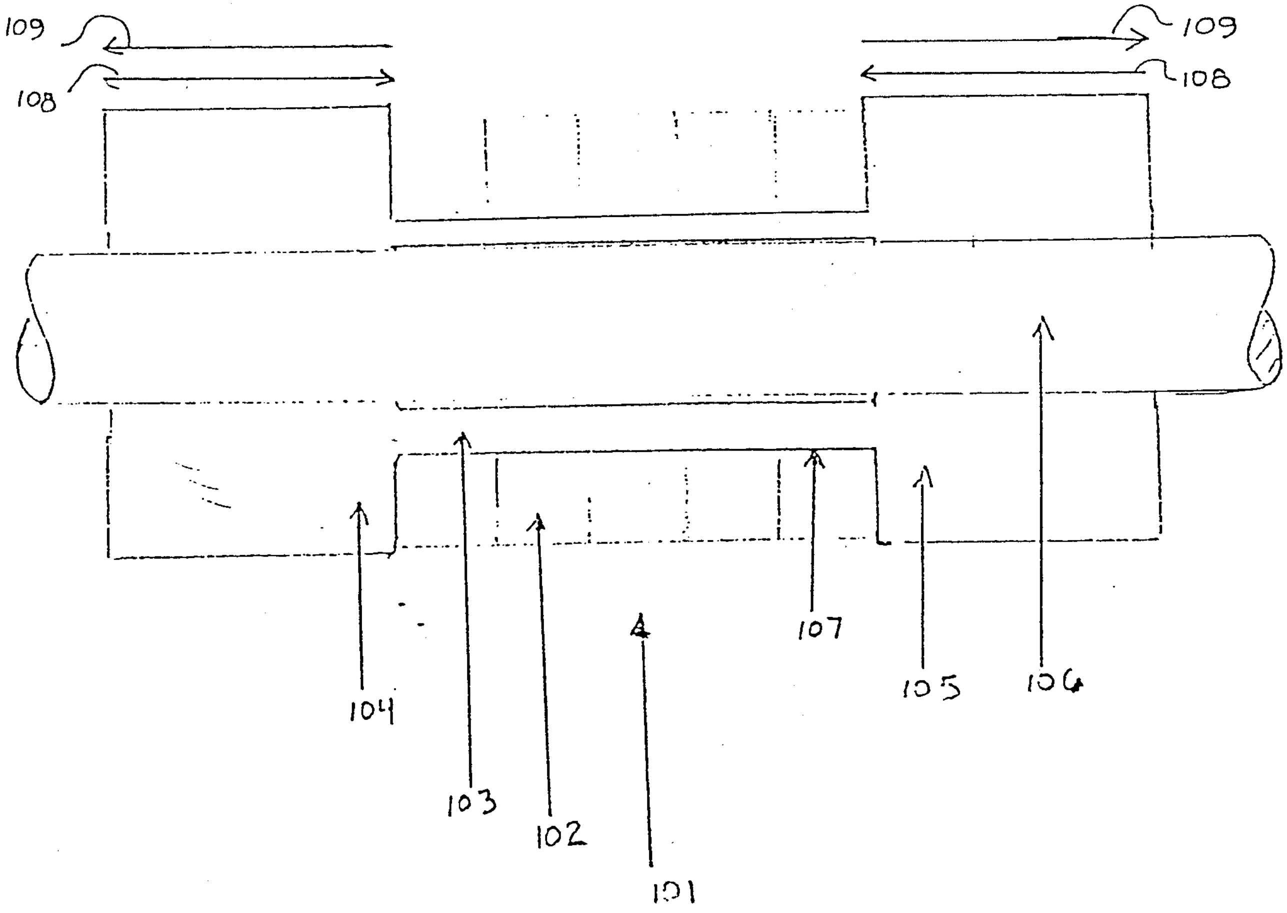

FIGURE 1
PRIOR ART

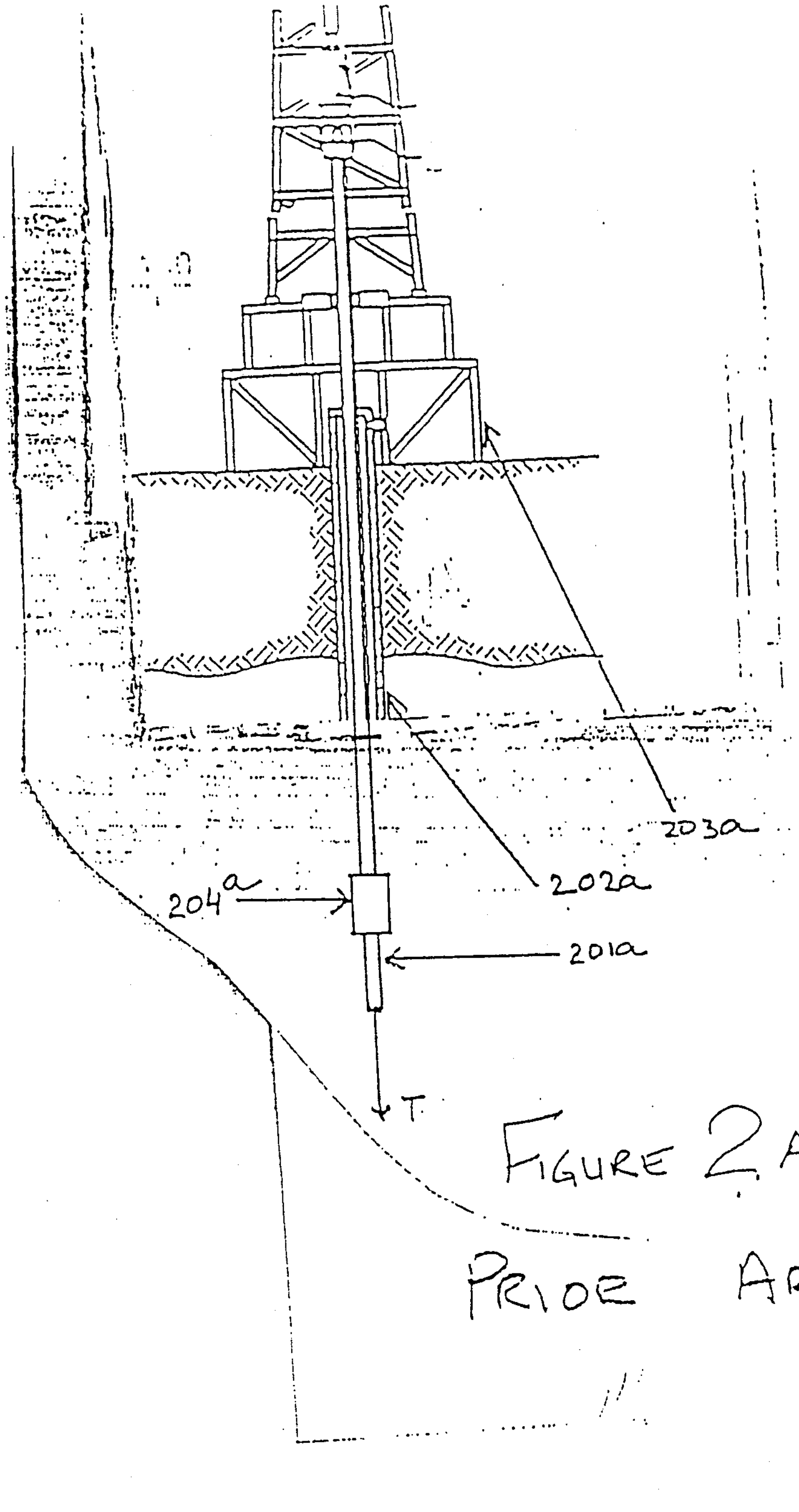

FIGURE 2A
PRIOR ART

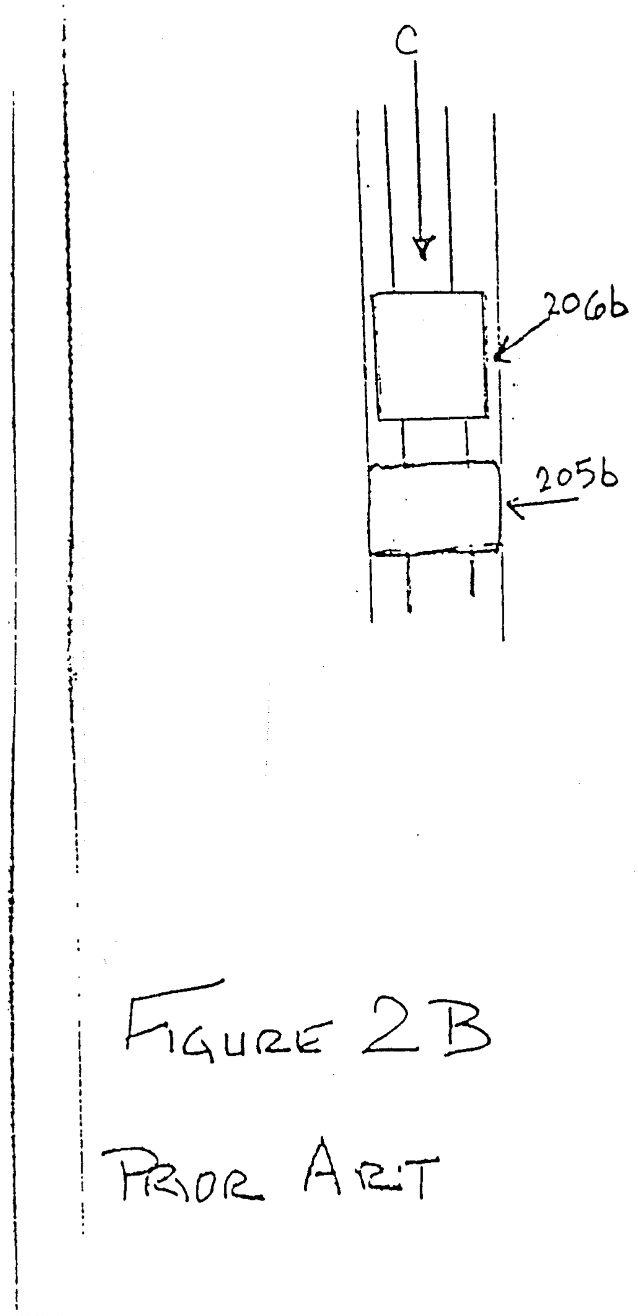

FIGURE 2B

PRIOR ART

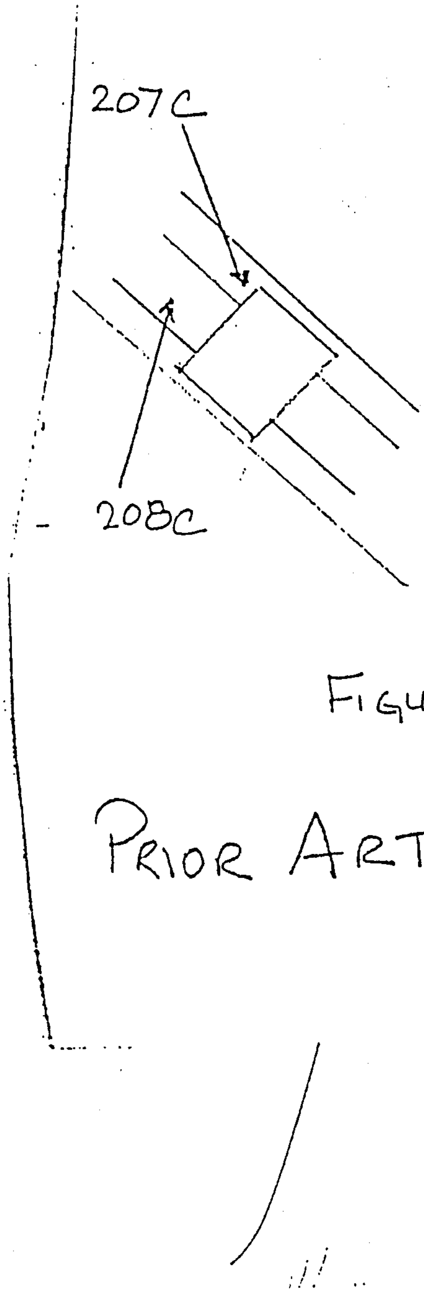

FIGURE 2C.

PRIOR ART

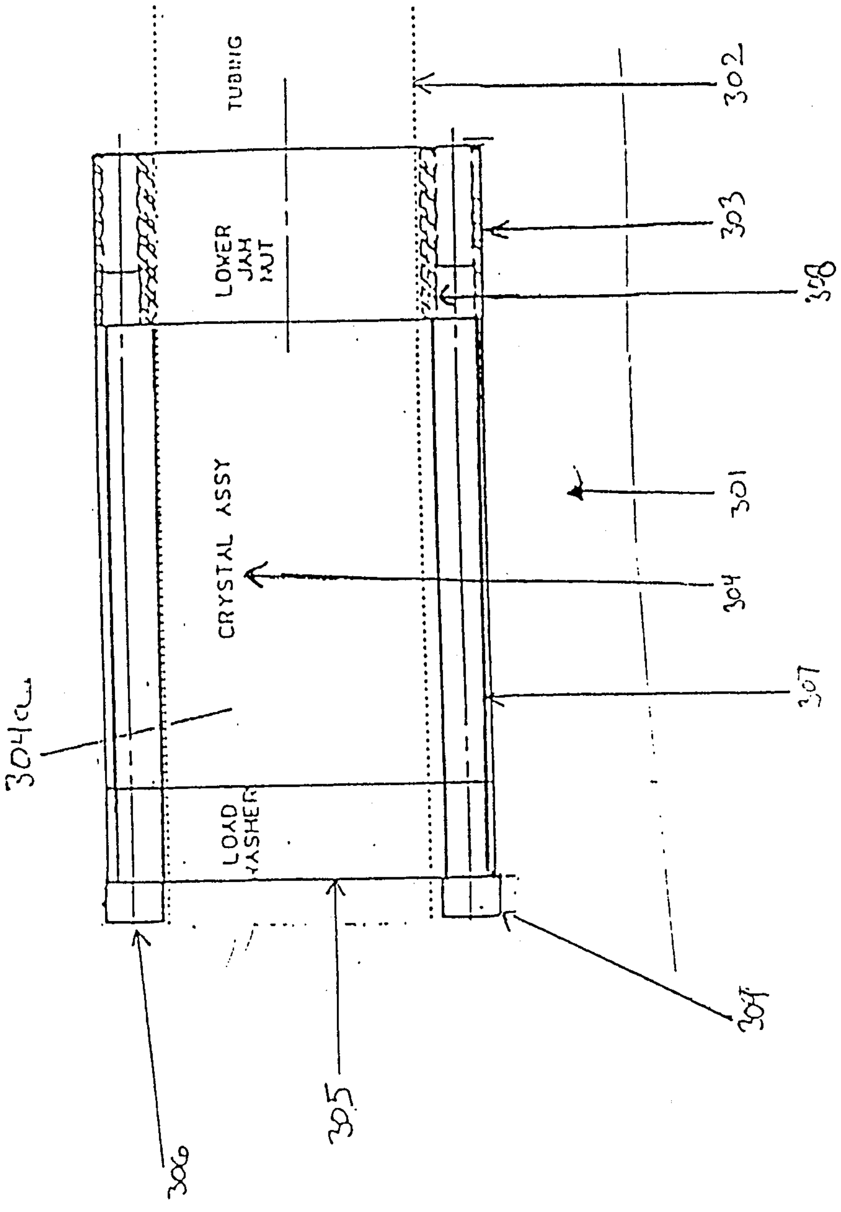
TUBING
LOWER JAM NUT
CRYSTAL ASSY
LOAD WASHER
302
303
308
301
304
307
309
305
306
304a

FIGURE 3

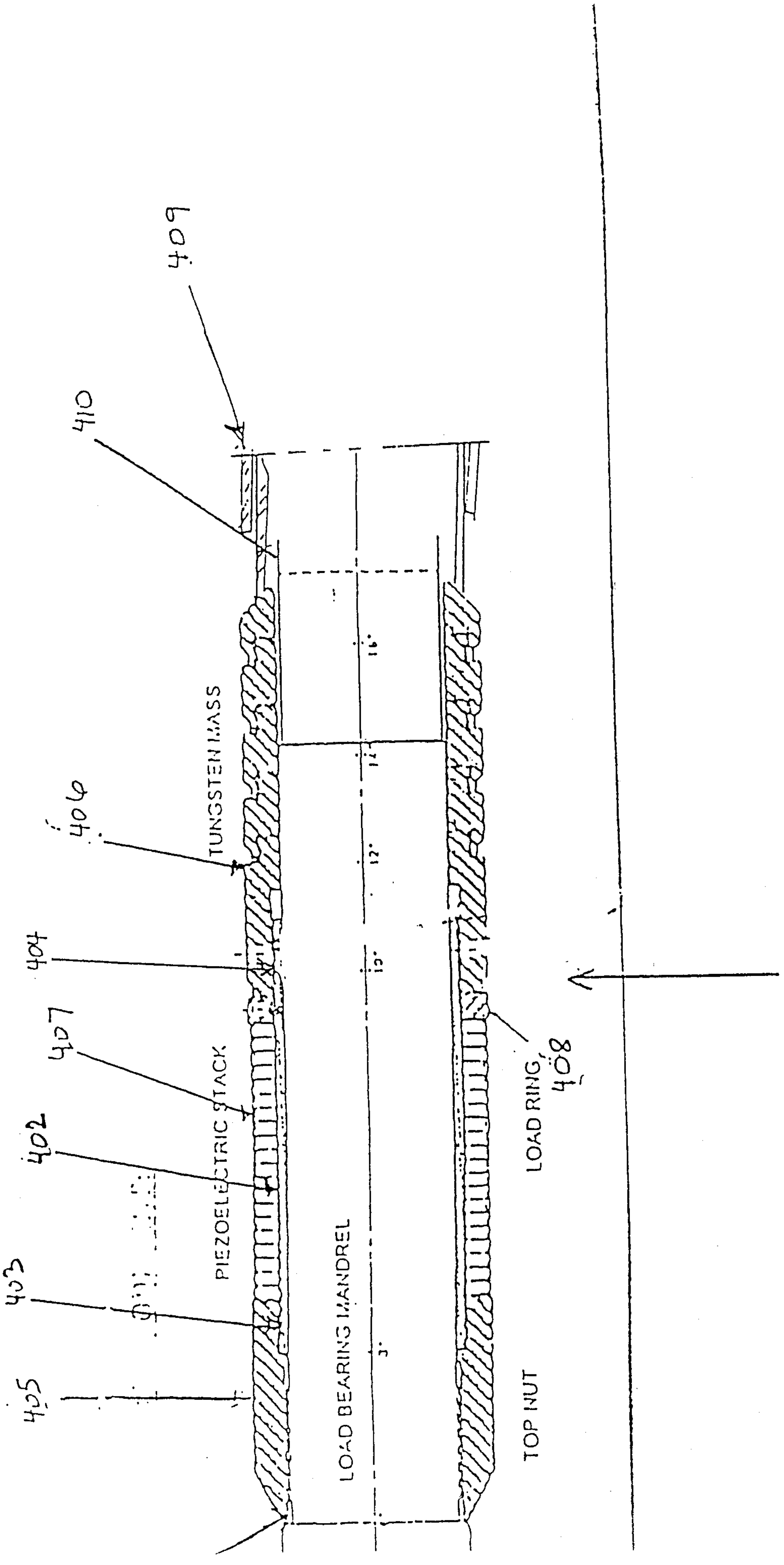
409
410
TUNGSTEN MASS
406
404
407
PIEZOELECTRIC STACK
402
403
405
LOAD BEARING MANDREL
LOAD RING
408
TOP NUT
401

FIGURE 4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/12002

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :H04H 9/00
US CL :367/81, 82
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)

U.S. : 367/81, 82

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

none

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

none

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,166,908 A (MONTGOMERY) 24 November 1992, see columns 3-6, 8-13.	1-16

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

*	Special categories of cited documents:	"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
"A"	document defining the general state of the art which is not considered to be of particular relevance		
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"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	"&"	document member of the same patent family

Date of the actual completion of the international search 18 AUGUST 1999	Date of mailing of the international search report 09 SEP 1999
Name and mailing address of the ISA US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer Timothy Edwards Joni Hill Telephone No. (703) 305-4896