

(19)



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(11)

EP 0 908 600 A2

(12)

EUROPEAN PATENT APPLICATION

(43) Date of publication:
14.04.1999 Bulletin 1999/15

(51) Int Cl.⁶: **E21B 47/06, E21B 47/18,
E21B 49/10, E21B 49/08**

(21) Application number: **98308218.1**

(22) Date of filing: **08.10.1998**

(84) Designated Contracting States:
**AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU
MC NL PT SE**
Designated Extension States:
AL LT LV MK RO SI

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(30) Priority: **09.10.1997 US 947805**

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(54) Formation testing apparatus

(57) A formation testing apparatus (10) for use within a wellbore (12). The apparatus (10) comprises a first fluid passage (22) for receiving fluid therein from a for-

mation (14) intersecting the wellbore (12). A first fluid pressure sensor (26) is interconnected to the first fluid passage (22). A filter (38) is coupled to the first pressure sensor (26).

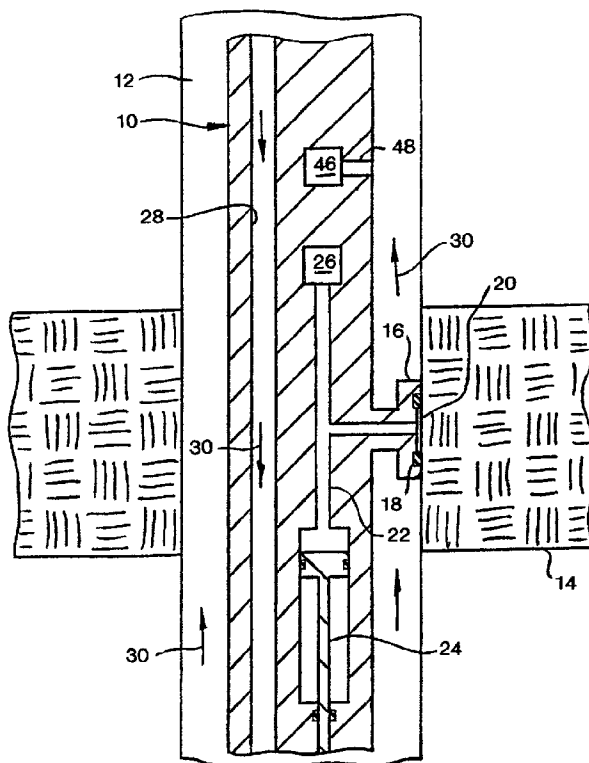


FIG. 1

EP 0 908 600 A2

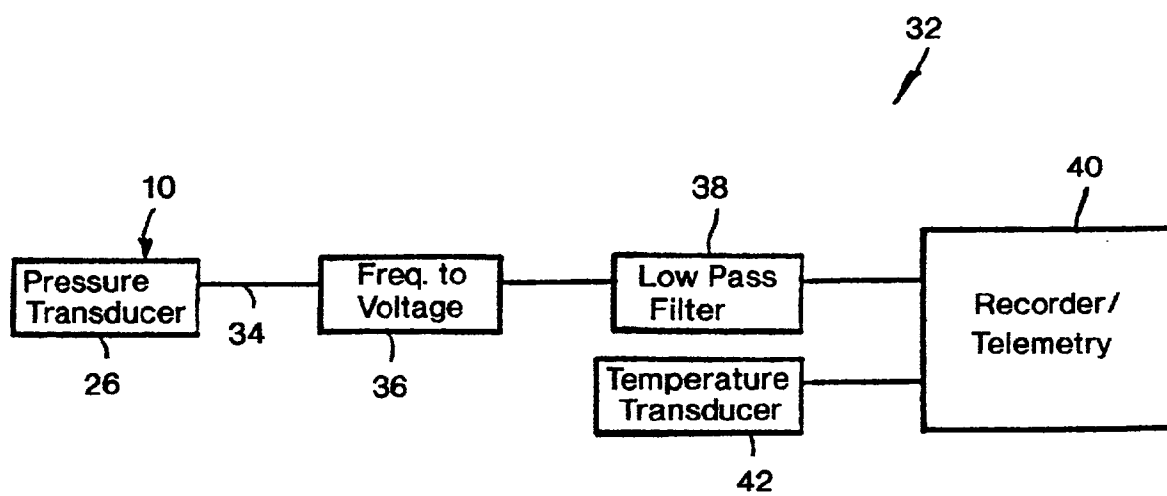


FIG. 3

Description

[0001] The present invention relates generally to operations and equipment for use in a subterranean well and, in an embodiment described herein, more particularly provides formation testing apparatus and methods of testing a formation. More particularly the present invention relates to formation testing apparatus, and associated methods, having noise reduction capability.

[0002] In operations performed in a subterranean well, it is quite common for data to be transmitted via fluid pressure pulses in the wellbore. This type of data transmission is typically referred to as "mud pulse telemetry". In a well known method of producing the fluid pressure pulses, fluid is circulated from the earth's surface to a downhole tool which periodically restricts, or otherwise changes, the rate of flow of the circulating fluid therethrough, thereby creating variations in the pressure of the circulating fluid. The pressure pulses (the frequency of which are typically on the order of about 1 Hz) are then detected at the earth's surface and the data decoded therefrom.

[0003] Unfortunately, such fluid pressure pulses may interfere with other operations in the well. For example, it is known that fluid pressure pulses may enter into a formation intersected by the wellbore and change the pressure of the fluid within the formation. This can result in inaccurate measurements of the formation fluid pressure taken by a formation testing tool.

[0004] In one type of formation testing tool, fluid is drawn into the tool from the formation. The pressure of the fluid is measured both before, during, and after it is drawn into the tool. These measurements are then utilized to calculate characteristics of the formation and predict its future productivity. Inaccuracies in these measurements may frustrate attempts to characterize the formation, leading to loss of production from the formation or loss of resources expended in producing the formation.

[0005] Since the accuracy of formation fluid pressure measurements is directly related to the economics of producing a well, it is generally considered prudent to ensure the highest possible accuracy of these measurements. Thus, it is typically not recommended to take formation fluid pressure measurements while simultaneously utilizing pressure pulse data transmission in the wellbore. As a result, this very useful form of data transmission is not available to transmit the formation fluid pressure measurements to the earth's surface for evaluation.

[0006] From the foregoing, it can be seen that it would be quite desirable to provide apparatus and methods which permit utilization of pressure pulse data transmission while simultaneously taking formation fluid pressure measurements. Additionally, apparatus and methods for eliminating the effects of extraneous fluid pressure pulses on formation fluid pressure measurements would be desirable as well. It is accordingly an object of

the present invention to provide such apparatus and methods.

[0007] In carrying out the principles of the present invention, in accordance with an embodiment thereof, apparatus is provided which is a formation testing tool. The tool is capable of taking accurate measurements of formation fluid pressure, even though the formation fluid pressure may be influenced by pressure pulses in the wellbore. Associated methods are also provided.

[0008] In broad terms, apparatus is provided which includes a pressure sensor coupled to an appropriately configured filter. The pressure sensor may be placed in fluid communication with a formation intersected by the well. An output of the pressure sensor may include combined indications of the formation fluid pressure and pressure pulses corresponding to the pressure pulses in the wellbore. The filter removes the pressure pulse indications from the pressure sensor output.

[0009] Where it is known that the pressure pulses have a frequency or frequencies different from a frequency or frequencies of the formation fluid pressure, the filter may be constructed to pass the formation fluid pressure frequencies while filtering out the pressure pulse frequencies. For example, if it is known that the formation fluid pressure frequency is less than the pressure pulse frequency, the filter may be provided as a low pass filter.

[0010] Other, more sophisticated filters may be utilized as well. For example, another pressure sensor may be provided and placed in fluid communication with the wellbore or other location in which the pressure pulses are transmitted. The output of this pressure sensor may then be coupled to the filter, so that the filter is capable of determining the contribution of the pressure pulses to the output of the formation fluid pressure sensor. The filter may then operate to remove this pressure pulse contribution from the formation fluid pressure sensor output. Examples of filters usable in the apparatus and having these capabilities are adaptive filters and neural network filters, which are well known to those of ordinary skill in the signal filtering art.

[0011] According to another aspect of the invention there is provided a formation testing apparatus for use within a wellbore, comprising a first fluid passage for receiving fluid therein from a formation intersecting the wellbore; a first fluid pressure sensor interconnected to the first fluid passage; and a filter coupled to the first pressure sensor.

[0012] The apparatus can be used within a wellbore of the type in which fluid pressure pulses having a first frequency are communicated with the formation. The apparatus can be used in a wellbore of the type in which the formation fluid pressure is influenced in part by pressure pulses in the wellbore.

[0013] The apparatus may further comprise a sealing device configured for sealingly engaging at least a portion of the formation, the sealing device being disposed relative to the first fluid passage such that the first fluid

passage is in fluid communication with the formation when the sealing device sealingly engages the formation.

[0014] In an embodiment the apparatus further comprises: a second fluid passage for receiving fluid therein from the wellbore; and a second fluid pressure sensor interconnected to the second fluid passage, the second pressure sensor being capable of sensing the fluid pressure pulses, and an output of the second pressure sensor being coupled to the filter. In this embodiment, the filter is preferably an adaptive filter or a neural network filter, rather than a low pass filter.

[0015] According to another aspect of the invention there is provided a fluid testing apparatus for use within a wellbore wherein fluid pressure pulses having a first frequency are communicated with a formation intersected by the wellbore, comprising: a first fluid passage for receiving fluid therein from the formation; a first fluid pressure sensor interconnected to the first fluid passage, the sensor being capable of sensing a combination of the fluid pressure pulses and the pressure of the fluid received from the formation, and the first pressure sensor producing an output; and a filter coupled to the first pressure sensor, the filter being capable of removing indications of the fluid pressure pulses from the first pressure sensor output.

[0016] In an embodiment, the filter is a low pass filter configured to remove the first frequency from the first pressure sensor output.

[0017] In an embodiment, a second fluid pressure frequency is imparted to the fluid received into the first fluid passage due to receiving the fluid into the first fluid passage, and the filter passes the second frequency but removes the first frequency from the first pressure sensor output. The second frequency may be less than the first frequency.

[0018] The low pass filter may be configured to pass frequencies less than a third frequency between the first and second frequencies. The low pass filter may be configured to pass frequencies up to and including the second frequency.

[0019] In an embodiment, the apparatus further comprises: a second fluid passage for receiving fluid therein from the wellbore; and a second fluid pressure sensor interconnected to the second fluid passage, the second pressure sensor being capable of sensing the fluid pressure pulses, and an output of the second pressure sensor being coupled to the filter.

[0020] The filter may be an adaptive filter capable of removing indications of the fluid pressure pulses from the first pressure sensor output based on the second fluid pressure sensor output.

[0021] The filter may be a neural network filter capable of removing indications of the fluid pressure pulses from the first pressure sensor output based on the second fluid pressure sensor output.

[0022] According to another aspect of the invention there is provided formation testing apparatus for sens-

ing the pressure of fluid received into the apparatus from a formation intersected by a wellbore, the formation fluid pressure being influenced in part by pressure pulses in the wellbore, the apparatus comprising: a sealing device configured for sealingly engaging at least a portion of the formation; a first fluid passage disposed relative to the sealing device such that the first fluid passage is in fluid communication with the formation when the sealing device sealingly engages the formation; a first fluid pressure sensor in fluid communication with the first fluid passage; and a filter coupled to the first fluid pressure sensor. The filter may be a low pass filter.

[0023] In an embodiment, the sealing device is configured to substantially isolate the portion of the formation from a portion of the wellbore when the sealing device sealingly engages the formation. In an embodiment, the apparatus further comprises a second fluid passage disposed relative to the sealing device such that the second fluid passage is in fluid communication with the portion of the wellbore and is capable of receiving the pressure pulses therein. The apparatus may further comprise a second fluid pressure sensor in fluid communication with the second fluid passage. The second pressure sensor may be coupled to the filter. The filter may be an adaptive filter or a neural network filter.

[0024] According to another aspect of the invention there is provided a method of measuring the pressure of fluid received in a testing apparatus from a formation intersected by a wellbore in the presence of fluid pressure pulses transmitted to the formation. the method comprising the steps of: interconnecting a first fluid pressure sensor to a first fluid passage in fluid communication with the formation; producing an output of the first pressure sensor including indications of the formation fluid pressure and the pressure pulses; coupling the first pressure sensor output to a filter; and filtering out the indications of the pressure pulses from the first pressure sensor output. The filter may be a low pass filter.

[0025] The filtering step may be performed by passing indications in the first pressure sensor output which have frequencies less than a predetermined frequency, and removing indications in the first pressure sensor output which have frequencies greater than the predetermined frequency.

[0026] The method may further comprise the steps of: interconnecting a second fluid pressure sensor to a second fluid passage in fluid communication with the wellbore; producing an output of the second pressure sensor including an indication of the pressure pulses; and coupling the second pressure sensor to the filter. The filtering step may further comprise adapting the filter to the indication of the pressure pulses output by the second pressure sensor. The filter may be an adaptive filter or a neural network filter.

[0027] According to another aspect of the invention there is provided a method of removing extraneous fluid pressure indications from an output of a first pressure sensor in fluid communication with a formation intersect-

ed by a wellbore, the method comprising the steps of: coupling the first pressure sensor output to a filter; and permitting indications in the first pressure sensor output other than the extraneous fluid pressure indications to pass through the filter. The filter may be a low pass filter.

[0028] The method may further comprise the steps of: coupling a second pressure sensor output to the filter. In the second pressure sensor output coupling step, the second pressure sensor output may include indications of the extraneous fluid pressure. The filter may be an adaptive filter or a neural network.

[0029] Reference is now made to the accompanying drawings, in which:

FIG. 1 is a schematicized cross-sectional view of a first embodiment of a formation testing tool according to the present invention;

FIG. 2 is a schematicized cross-sectional view of a second embodiment of a formation testing tool according to the present invention;

FIG. 3 is a block diagram of a first embodiment of a method according to the present invention; and

FIG. 4 is a block diagram of a second embodiment of a method according to the present invention.

[0030] Representatively illustrated in FIG 1 is a formation testing tool 10 which embodies principles of the present invention. In the following description of the tool 10 and other apparatus and methods described herein, directional terms, such as "above", "below", "upper", "lower", etc., are used for convenience in referring to the accompanying drawings. Additionally, it is to be understood that the various embodiments of the present invention described herein may be utilized in various orientations, such as inclined, inverted, horizontal, vertical, etc., without departing from the principles of the present invention.

[0031] The tool 10 is shown disposed within a wellbore 12 of a well. The wellbore 12 intersects a formation, or interval of a formation, 14 from which it is desired to obtain fluid pressure measurements. The tool 10 is of the well known type which has a laterally outwardly extendable fluid sampling portion 16 including a sealing device 18 for contacting and sealingly engaging the formation 14. In this manner, a portion 20 of the formation 14 is substantially isolated from the remainder of the wellbore 12 external to the sealing device 18.

[0032] A fluid passage 22 extends into the interior of the tool 10 and is in fluid communication with the formation portion 20. When a piston 24 is stroked downwardly as viewed in FIG. 1, fluid is drawn into the fluid passage 22 from the formation 14. The pressure of the formation fluid is sensed by a fluid pressure sensor 26, which is in fluid communication with the fluid passage 22.

[0033] An axial fluid conduit 28 is formed through the tool 10. Via a tubular string (not shown) attached to the tool 10 and extending to the earth's surface, the fluid conduit 28 is utilized to permit circulation of fluid (indi-

cated by arrows 30), such as drilling mud, downwardly through the tool 10 and then axially upward back to the earth's surface through the wellbore 12. Other equipment, such as conventional mud motors, mud pulse telemetry tools, tubular strings, etc. (not shown) may be connected to the tool 10 and extend downwardly therefrom.

[0034] In one manner in which fluid pressure pulses may be induced in the fluid 30, a mud pulse telemetry tool may be utilized to generate data-carrying pressure pulses in the circulating fluid, so that the pressure pulses may be received at the earth's surface and decoded. Of course, pressure pulses may be present in the fluid 30 due to other causes, may be present whether or not the fluid is simultaneously being circulated through the well, and the fluid may be circulated in a reverse direction or not circulated at all. Thus, other pressure pulse sources and other dispositions of the fluid 30 may be utilized without departing from the principles of the present invention.

[0035] The fluid 30 contacts the formation 14, even though it may be substantially isolated from the formation portion 20 by the sealing device 18. It will be readily appreciated by one of ordinary skill in the art that pressure pulses in the fluid 30 may be transmitted into the formation 14 via those areas of the formation intersected by the wellbore 12 and external to the sealing device 18. It will also be appreciated that the pressure pulses may be transmitted through the formation 14 to the portion 20 and influence the pressure of the formation fluid drawn into the fluid passage 22. Thus, the pressure sensor 26 may produce an output which indicates a combination of the formation fluid pressure and the pressure pulses transmitted into and through the formation 14 to the portion 20.

[0036] In an important aspect of the present invention, the tool 10 includes features which remove the indications of the pressure pulses from the pressure sensor 26 output, thereby enhancing the accuracy of the formation fluid pressure measurements obtained by the tool. One method 32 of accomplishing this objective is representatively illustrated in block diagram form in FIG. 3. The pressure sensor 26 is shown as a pressure transducer whose output 34 is coupled via a frequency to voltage converter 36 to a low pass filter 38.

[0037] The use of the frequency to voltage converter 36 is preferred where the pressure sensor 26 is of the type which has a frequency output 34. However, where a sensor 26 having a voltage output is used, the converter 36 is not needed. Additionally, it is to be clearly understood that it is not necessary for the pressure sensor output 34 to be voltage modulated, or for the output to be converted from frequency to voltage modulated, in accordance with the principles of the present invention.

[0038] The filter 38 is preferably a low pass filter as shown in FIG. 3. It is believed that, in most circumstances, the frequency of the pressure pulses transmitted

from the fluid 30, through the formation 14 and to the portion 20 will be substantially greater than the frequency of the formation fluid pressure which would be sensed in the absence of the pressure pulses. For example, the frequency of the pressure pulses may be about 1 Hz, while the formation fluid pressure may be about 0.5 Hz (due to drawdown of fluid from the formation 14 into the tool 10, and subsequent fluid pressure buildup, etc.)

[0039] Therefore, the filter 38 may be configured to pass the formation fluid pressure frequencies but block passage of the pressure pulse frequencies. For example, the filter 38 could be configured to pass frequencies less than about 0.75 Hz, but block frequencies above about 0.75 Hz. As another example, the filter 38 may be configured to pass frequencies equal to or less than the formation fluid pressure frequency. Of course, other types of filters may be used for the filter 38, and other configurations of the filter may be utilized, without departing from the principles of the present invention.

[0040] In the method 32, the pressure sensor output 34, with the indications of the pressure pulses removed therefrom by the filter 38, is connected to a conventional recorder and/or telemetry module 40. In this manner, the output 34 may be recorded in the tool 10 for later retrieval, or transmitted directly to the earth's surface, for example, via mud pulse telemetry, other acoustic telemetry, electromagnetic waves, wireline connected to the tool 10, etc. Other sensors and types of sensors may be connected to the recorder/telemetry module 40 as well. For example, a temperature sensor 42 may be included in the tool 10 for measuring the temperature of the formation fluid or of the wellbore 12 at the formation 14.

[0041] Another method 44 of enhancing the accuracy of the formation fluid pressure measurements taken by the tool 10 is representatively depicted in block diagram form in FIG. 4. The method 44 utilizes an additional pressure sensor 46 to detect the pressure pulses in the wellbore 12. Referring again to FIG. 1, the sensor 46 may be seen included in the tool 10 and in fluid communication with a fluid passage 48 which, in turn, is in fluid communication with the wellbore 12. Of course, if the method 32 is utilized instead of the method 44, the additional sensor 46 and fluid passage 48 are not needed in the tool 10.

[0042] In the method 44, the output 34 of the sensor 26 (which includes indications of both the pressure pulses and of the formation fluid pressure) and an output 50 of the sensor 46 (which includes an indication of the pressure pulses in the fluid 30) are coupled to a filter 52. The filter 52 is of the type that removes extraneous signals (also termed "noise") based at least in part on a separate detection of the extraneous signals. This type of filter is well known to a person of ordinary skill in the signal filtering art and examples thereof may be found in a publication entitled Neural Network Design by M.T. Hagan et al., published in 1996 by PWS Publishing Co., Boston, Mass., the disclosure of which is incorporated herein by this reference. Another example of a type of

filter which may be used for the filter 52 is an adaptive filter, also well known to a person of ordinary skill in the art.

[0043] Referring additionally now to FIG. 2, another formation testing tool 54 embodying principles of the present invention is schematically and representatively illustrated. Elements shown in FIG. 2 which are similar to those previously described are indicated in FIG. 2 using the same reference number, with an added suffix "a".

[0044] The tool 54 is of the type having an upper portion 56 axially reciprocally disposed relative to a lower portion 58. The lower portion 58 is positioned opposite the formation 14a and a pair of axially spaced apart inflatable packer elements 60 are inflated, so that they radially outwardly extend into sealing engagement with the formation 14a. In this manner, a portion 62 of the formation 14a is substantially isolated from the remainder of the wellbore 12a. An example of this type of tool is the RT031 and RT032 available from Halliburton Energy Services.

[0045] Note that the portion 62 differs from the previously described portion 20 in that the portion 62 extends circumferentially about the tool 54 and the packer elements 60 effectively isolate an upper portion 64 of the wellbore 12a from a lower portion 66 of the wellbore. However, it will be readily appreciated by a person of ordinary skill in the art that, if pressure pulses are present in the wellbore 12a, these pressure pulses may still affect the formation fluid pressure at the formation portion 62. The fluid passage 22a is in fluid communication with the formation portion 62, and so, when the upper tool portion 56 is axially upwardly displaced relative to the lower portion 58, fluid from the formation 14a is drawn into the fluid passage 22a, and its pressure is measured by the pressure sensor 26a.

[0046] The pressure pulses in the wellbore 12a may be caused by mud pulse telemetry or may originate at another source. If mud pulse telemetry is utilized, the fluid 30a may be circulated from the earth's surface downwardly through a tubular string (not shown) attached above the tool 54, outwardly through a radially extending fluid passage 68 to the upper wellbore portion 64, and upwardly to the earth's surface. Thus, the pressure pulses may be present in the upper wellbore portion 64, but not in the lower wellbore portion 66. Nevertheless, the pressure pulses may still be communicated through the formation 14a to the portion 62.

[0047] If the method 32 is utilized with the tool 54, then only one pressure sensor 26a may be used in the tool. However, if the method 44 is utilized, the additional pressure sensor 46a may be installed in the tool 54 with the fluid passage 48a providing fluid communication between the wellbore 12a and the pressure sensor 46a. Of course, if the pressure pulses are present in the upper wellbore portion 64, but not in the lower wellbore portion 66, the fluid passage 48a should be in fluid communication with the upper wellbore portion, but it may additionally be placed in fluid communication with the

lower wellbore portion 66 if desired.

[0048] It may now be fully appreciated that, if the method 32 is utilized with the tool 54, that the pressure sensor 26a may be coupled to the filter 38, and that if the method 44 is utilized with the tool 54, both of the pressure sensors 26a, 46a may be coupled to the filter 52. Thus, the tool 54 demonstrates that the methods 32, 44 may be utilized with a variety of tools, that it is not necessary for the pressure pulses to be present in the entire wellbore, and that other manners of sealingly engaging and drawing fluid from the formation 14a may be utilized, without departing from the principles of the present invention.

[0049] Of course, a person of ordinary skill in the art would find it obvious to make modifications, substitutions, additions, deletions, and other changes to the tools 10, 54 and methods 32, 44 described herein, and such changes are contemplated by the principles of the present invention. Accordingly, the foregoing detailed description is to be clearly understood as being given by way of illustration and example. It will be appreciated that the invention may be modified.

Claims

1. A formation testing apparatus for use within a wellbore (12,12a), comprising a first fluid passage (22,22a) for receiving fluid therein from a formation (14,14a) intersecting the wellbore (12,12a); a first fluid pressure sensor (26,26a) interconnected to the first fluid passage (22, 22a); and a filter (38) coupled to the first pressure sensor (26, 26a).
2. Apparatus according to claim 1, for use within a wellbore (12) in which fluid pressure pulses having a first frequency are communicated with the formation (14) intersected by the wellbore (12), wherein the first fluid pressure sensor (26) is capable of sensing a combination of the fluid pressure pulses and the pressure of the fluid received from the formation (14), wherein the first pressure sensor (26) produces an output, and wherein the filter (38) is capable of removing indications of the fluid pressure pulses from the first pressure sensor output.
3. Apparatus according to Claim 2, wherein the filter (38) is a low pass filter (38) and is configured to remove the first frequency from the first pressure sensor output.
4. Apparatus according to Claim 2 or 3, wherein a second fluid pressure frequency is imparted to the fluid received into the first fluid passage (22) due to receiving the fluid into the first fluid passage (22), and wherein the filter (38) passes the second frequency but removes the first frequency from the first pressure sensor output.
5. Apparatus according to Claim 4, wherein the second frequency is less than the first frequency.
6. Apparatus according to any preceding Claim, further comprising: a second fluid passage (48) for receiving fluid therein from the wellbore (12); and a second fluid pressure sensor (46) interconnected to the second fluid passage (48), the second pressure sensor (46) being capable of sensing the fluid pressure pulses, and an output of the second pressure sensor (46) being coupled to the filter (38).
7. Apparatus according to claim 1, for use in sensing the pressure of fluid received into the first fluid passage (22a) from the formation (14a), the formation fluid pressure being influenced in part by pressure pulses in the wellbore (12a), further comprising a sealing device (60) configured for sealingly engaging at least a portion of the formation (14a), the sealing device (60) being disposed relative to the first fluid passage (22a) such that the first fluid passage (22a) is in fluid communication with the formation (14a) when the sealing device (60) sealingly engages the formation (14a).
8. Apparatus according to Claim 7, wherein the sealing device (60) is configured to substantially isolate the portion of the formation (14a) from a portion of the wellbore (12a) when the sealing device (60) sealingly engages the formation (14a), and further comprising a second fluid passage (48a) disposed relative to the sealing device (60) such that the second fluid passage (48a) is in fluid communication with the portion of the wellbore (12a) and is capable of receiving the pressure pulses therein.
9. Apparatus according to Claim 8, further comprising a second fluid pressure sensor (46a) in fluid communication with the second fluid passage (48a).
10. Apparatus according to Claim 9, wherein the second pressure sensor (46a) is coupled to the filter (38).

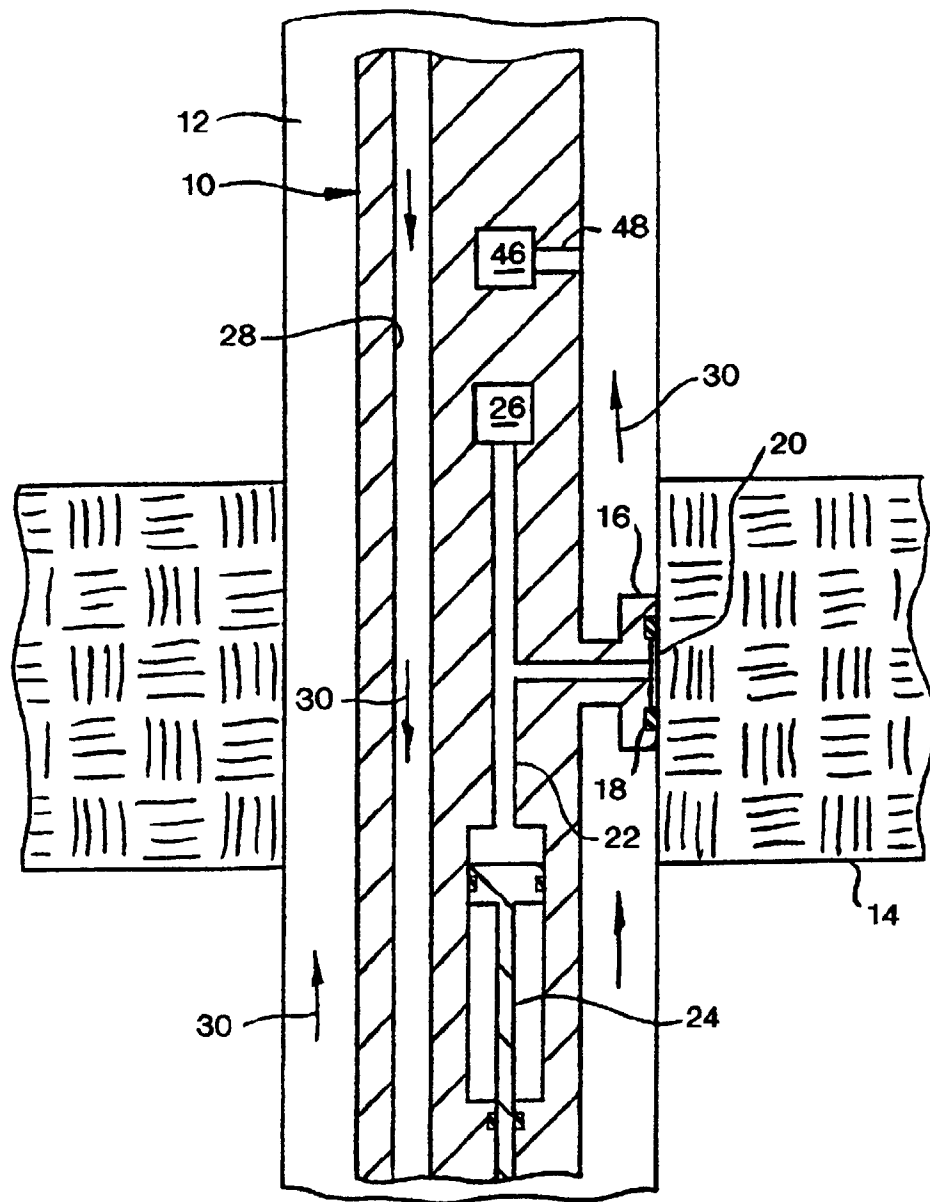


FIG. 1

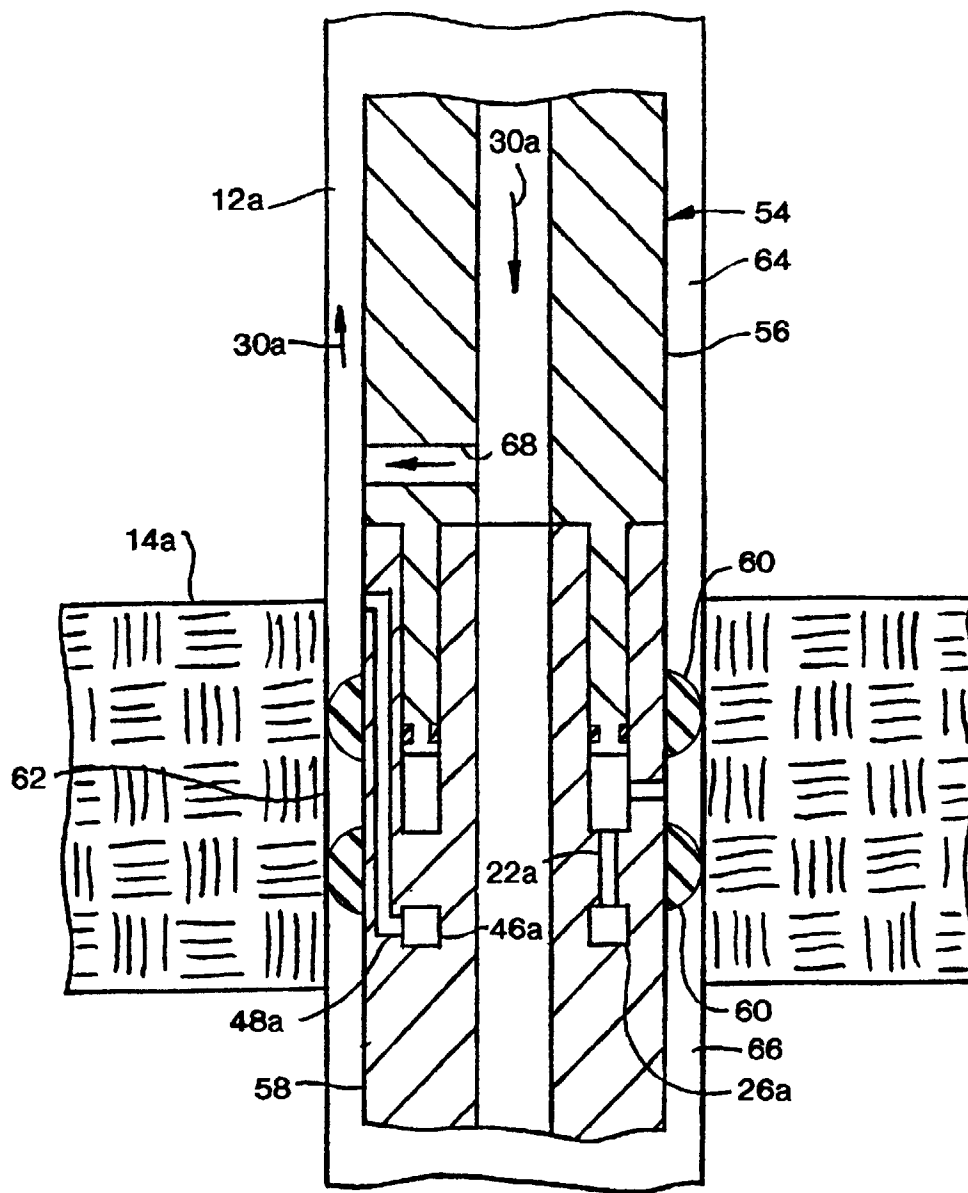


FIG. 2

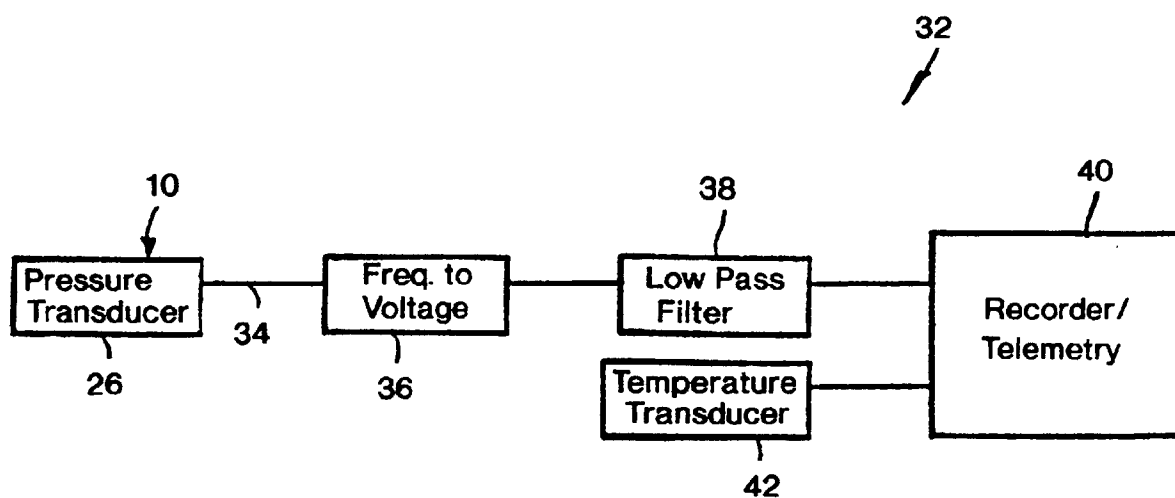


FIG. 3

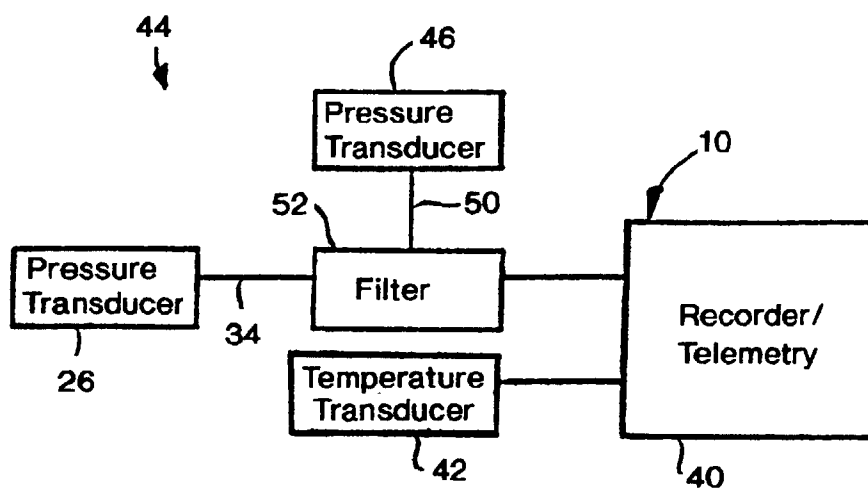


FIG. 4