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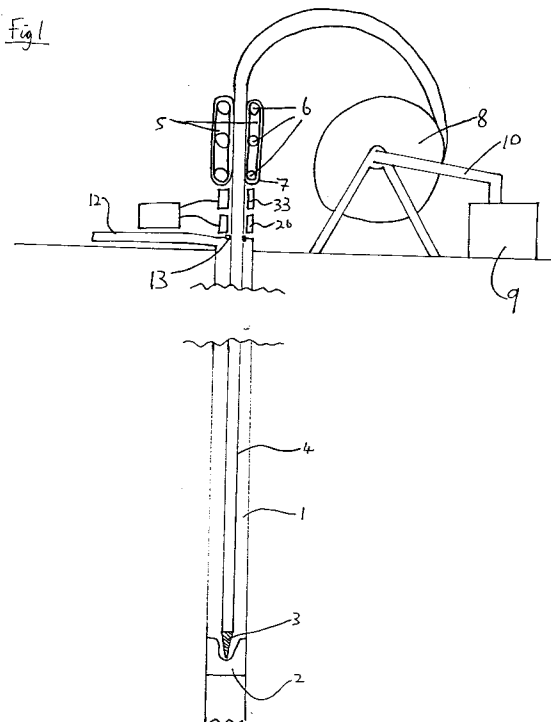
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(54) **Data transmission along a borehole.**

(57) Data from an effector at the end of a pipe in a borehole is transmitted to the surface as acoustic compression waves in the pipe. Similarly instructions can be passed from the surface to the end effector by acoustic compression waves in the pipe.

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This invention relates to data transmission, and particularly to data transmission along a borehole.

After a borehole has been drilled, for example to produce oil, it is often necessary to carry out operations within it. These operations include inspection of the borehole walls, the formation and removal of plugs and treating the borehole wall to increase fluid flow rates among others.

One method of doing this is to pass a narrow bore continuous tube with a sensor or end effector at its end down the borehole. In order to monitor and control this sensor/effector data must be passed up the borehole and instructions must be passed down. This is done using a cable such as a multi-core or coaxial cable, passing down the centre of the tube.

There are three main problems associated with this technique, the first is that the environment at the bottom of the borehole can be very different from that at the top, temperatures up to 200° C and pressures of 15,000 pSi can be encountered at the bottom of a borehole. This can cause considerable problems as the electrical properties of the cable change as the environment around it changes resulting in a wire having different characteristics along its length. This can result in unacceptable electrical attenuation in signals passing along the cable. Secondly, in addition to the changes in conditions along the borehole's length conditions within the tube are extremely hostile, apart from the pressures and temperatures naturally present within the borehole it is often necessary to pump fluid under high pressure down the pipe to power end effectors such as drills. This produces an unacceptably high rate of cable failures, and withdrawing the pipe and replacing the cable is both time consuming and costly. The third problem is that the lengths of the cable and tube must of course be matched precisely and the length of the tube must be matched to the depth in the borehole at which the work or examination is to be done and as a result a very large number of tubes and cables must be held as stock at great expense, which is clearly undesirable.

This invention was intended to produce a data transmission system at least partially overcoming these problems.

This invention provides a data transmission system for use in a borehole comprising a first acoustic transducer, a second acoustic transducer and a continuous solid element, the first acoustic transducer being associated with the element at a first point and the second acoustic transducer being associated with the element at a second point spaced apart from the first, the first transducer being arranged to produce acoustic waves in the element and the second transducer being arranged to detect these acoustic waves.

This allows communication between the end of a pipe in a borehole and the surface using the pipe itself to carry the signal; this eliminates the problem of cable failure and because the acoustic properties of the pipe will not change in such a way as to prevent acoustic wave transmission due to the pressure and temperature changes encountered within boreholes the problem of variable attenuation with the signals will be reduced. Since no cable is needed within the pipe the amount of stock which must be held is reduced, saving money.

Advantageously acoustic compression waves are used because the amplitude of acoustic compression waves decays more slowly over distance than acoustic transverse waves, in other words they suffer fewer losses, and they travel faster, commonly up to 10 times faster than acoustic transverse waves in metal pipes.

It is desirable to have the facility for two way signal traffic along the element, often data must be passed from sensors down a borehole to a controller on the surface who sends instructions back down the borehole to an effector associated with the sensor. This can be achieved either by making each transducer both an acoustic wave producer and detector or by having a third transducer local to the second point and a forth transducer local to the first point and having the third transducer arranged to produce acoustic waves and the forth transducer arranged to receive them.

Preferably the element is a continuous metal tube because this allows a pipe in a borehole to be used to carry the acoustic waves and a pipe forms a very good carrier of acoustic compression waves.

Advantageously the element is a pipe down a borehole and the first and second points are inside and outside the borehole respectively, allowing data to be carried from a sensor down a borehole to the surface.

Apparatus employing the invention will now be described by way of example only with reference to the accompanying diagrammatic figures in which:

Figure 1 shows an overall view of a data transmission system linking a device down a borehole with the surface;

Figure 2 shows the device down the borehole in more detail; and

Figure 3 shows the apparatus on the surface in more detail, similar parts having the same reference numerals throughout.

Referring to Figure 1 a borehole 1 is shown, only the top and bottom of the borehole 1 are illustrated, the central region of the borehole 1 being omitted. In the borehole 1 is a concrete plug 2 which blocks the borehole 1. In order to remove the concrete plug 2 a drill 3 on the end of a continuous steel pipe 4 is passed down the

borehole 1.

The pipe 4 does not rotate but is fed up and down the borehole 1 by two beltdrives 5. The two beltdrives 5 are spaced symmetrically around the pipe 4 and each comprise motor driven wheels 6 urged against the pipe 4 and running within a belt 7, each beltdrive 5 operating in a similar manner to a caterpillar track. By altering the motor power applied to the belt drives 5, not only can the pipe 4 be moved up and down the borehole 1, but the force with which the drill 3 is urged against the concrete plug 2 can be altered.

The motor system powering the beltdrives 5 are omitted for simplicity since beltdrives of this type are well known and need not be described in detail here.

As the pipe 4 is fed up and down the borehole 1 the surplus pipe 4 is removed from or added to a reel 8.

The pipe 4 does not rotate, so in order to power the drill 3 fluid is pumped down the interior of the pipe 4 by a pump 9 which is linked to the end of the pipe 4 by a pipe 10. This fluid is used to drive the drill 3 by way of a turbine 11. After passing through the turbine 11 the fluid passes out of the pipe 4 and passes back up the borehole 1 around the pipe 4 to the surface. At the surface the fluid leaves the borehole 1 and passes along a pipe 12 and is dumped. At the top of the borehole 1 a seal 13 is provided to allow the pipe 4 to move without allowing the fluid to escape.

Referring to Figure 2 the bottom end of the pipe 4 is shown in more detail. Fluid passes down the bore of the pipe 4, and into a tapered section 14 leading to a narrow bore section 15. The tapered and narrow bore sections 14 and 15 are defined by an inner tube 16 arranged coaxially within the tube 4 to leave an annular gap 17 between the two tubes 4 and 16.

When the fluid reaches the end of the tubes 4 and 16 it passes through the turbine 11 attached to the drill 3 and exits from the periphery of the turbine 11 into the borehole 1. Thus the pressure of the fluid drives the drill 3.

The annular gap 17 contains the electronics used to transfer data between the bottom and top of the borehole 1.

A rotational transducer 18 senses the rotation of the drill 3 and produces electrical signals giving the speed of rotation of the drill 3 and supplies them to a data acquisition system 19. A force transducer 20 senses the force exerted on the drill 3 by the tube 4 and supplies electrical signals containing this information to the data acquisition system 19. A pressure transducer 21 senses the pressure of the fluid passing down the tube 4 and supplies electrical signals containing this information to the data acquisition system 19.

The data acquisition system 19 marshals the data from the three transducers 18, 20 and 21 into a serial data stream and adds error correction codes. It then supplies this data stream to a first acoustic transducer 22 which converts the data stream into a series of acoustic compression waves in the wall of the pipe 4. The first acoustic transducer 22 is linked to the pipe 4 by an acoustic impedance matching element 23.

A forth acoustic transducer 24 senses acoustic compression waves in the pipe 4 and converts them into electrical signals which are supplied to the data acquisition system 19.

The electronics at the bottom of the pipe 4 are all powered by a battery 25.

Referring to Figure 3, at the top of the borehole 1 the pipe 4 passes through a sliding seal 13 which allows the pipe to move up and down the borehole 1 without allowing the fluid to escape.

A second acoustic transducer 26 is situated adjacent the pipe 4 above the sliding seal 13, the second acoustic transducer 26 is a non-contact magnetic transducer which produces electrical signals corresponding to longitudinal movements of the pipe 4. These signals are supplied to a processor 27. The processor 27 analyses the signals from the second transducer 26 and extracts the parts of the signal relating to acoustic compression waves in the wall of the pipe 4, rejecting noise due to the various pieces of moving machinery associated with the pipe 4, such as reel 8, beltdrives 5, pump 9 and the drill 3, and also rejecting signals produced by the movement of the pipe 4 in the borehole 1.

The processor 27 reconstructs the data stream sent by the data acquisition system 19 using the error correction codes to replace any data which has been lost. Data can be lost due to destructive interference or being swamped by noise.

The processor 27 also receives data on lines 28 from sensor at the top of the borehole 1, this data gives the pressure at which fluid is pumped into the pipe 4 by the pump 9 and the length of pipe 4 within the borehole 1, which is derived from the rotational movement of the reel 8.

The processor 27 displays all of this data on a visual display unit (V.D.U.) 29 and stores it in a first memory 30. The processor compares the data with its instructions stored in a second memory 31 and decides what actions are necessary.

The processor 27 then instructs the beltdrives 5 and pump 9 as necessary along lines 32 and organises instructions for the elements at the bottom of the pipe 4 as a serial data stream and adds error correction codes. It then supplies this serial data stream to a third acoustic transducer 33 which is a non-contact magnetic transducer which converts the data stream into acoustic compression

waves in the pipe 4.

If necessary the instructions stored in the first memory 30 can be altered by commands along a line 34, this line 34 can also be used to instruct the processor 27 directly.

When the compression waves generated by the third transducer 33 reach the bottom of the pipe 4 they are picked up by the forth transducer 24 and supplied to the data acquisition system 19. This reconstructs the data stream using the error correction codes to replace any lost data in the same way as the processor 27 and takes the action the data stream instructs it to take.

The forth transducer 24 will of course pick up the acoustic waves generated by the first acoustic transducer 22 in the pipe 4, similarly the second transducer 26 will pick up the acoustic waves generated by the third transducer 33. In both cases the signal processor, data acquisition system 19 and processor 27 respectively, will ignore the acoustic waves it has produced itself.

In the example above although there is little that the system at the bottom of the pipe 4 can do in response to instructions from above because it does not include an end effector, it is useful to be able to pass instructions to repeat signals or initiate self-test procedures or to go into or out of power conserving modes. In other types of end effector fitted to the pipe 4 more instructions may be necessary, possible end effectors could be anything used in borehole logging including for example, cement layers, inflatable plugs, grabs, perforators to modify the walls of the borehole 1, sensitive signal generators or receivers, neutron flux detectors resistivity measurement tools and ultrasonic or TV scanners.

In the case of seismic signal generators or ultrasonic or TV scanners in particular a high data rate for transmission up the pipe 4 is desirable.

Error correction code systems suitable for transmitting data in a high noise environment are well known per se, so it is unnecessary to describe them in detail here.

Although the example described uses acoustic compression waves to pass data along a continuous pipe a similar system could be used for communication anywhere where a continuous link of a material with good acoustic properties exists, for example railway signalling systems and trains could communicate by acoustic compression waves along railway lines and pumping stations could communicate among themselves and with pipeline "pigs" by acoustic compression waves along metal pipelines. The precise form of the systems for producing and sensing the acoustic waves will depend on the system and the characteristics of the transmitting member and the amount and type of relative movement between the

transmitting member and the producing or sensing element.

Although acoustic compression waves are used in the example above, acoustic transverse waves could be used, however compression waves are preferred because they travel faster and generally suffer fewer losses.

It may be preferred to provide the forth transducer 24 with an impedance matching element similar to the impedance matching network 23.

Instead of having separate transmitting transducers 22 and 26 and receiving transducers 24 and 33 a single transmitting and receiving transducer could be used at the lower end of the drill pipe 4 or on the surface, however this would require careful synchronisation of the data acquisition system 19 and the processor 27 to ensure that data was not lost due to a transducer transmitting while acoustic waves from the other end of the drill pipe 4 were arriving at it.

The transducer 26 is a non-contact magnetic transducer so that it can detect acoustic waves in the pipe 4 without interfering with movements of the pipe 4. Alternatively, other types of transducers could be used such as an accelerometer or a piezoelectric transducer as used in a record stylus.

Although the use of a steel pipe 4 is described this invention could be employed with pipes of any other metal or alloy, or even with other materials such as plastics provided they had suitable acoustic propagation properties.

Claims

1. A data transmission system for use in a borehole comprising a first acoustic transducer, a second acoustic transducer and a continuous solid element, the first acoustic transducer being associated with the element at a first point and the second acoustic transducer being associated with the element at a second point spaced apart from the first, the first transducer being arranged to produce acoustic waves in the element and the second transducer being arranged to detect these acoustic waves.
2. A data transmission system as claimed in claim 1 in which the second transducer is also arranged to produce acoustic waves in the element and the second transducer is also arranged to detect these acoustic waves.
3. A data transmission system as claimed in claim 1 in which a third acoustic transducer is associated with the element local the second point and a forth acoustic transducer is associated with the element local the first point, the

third transducer being arranged to produce acoustic waves in the element and the forth transducer being arranged to detect these acoustic waves.

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4. A data transmission system as claimed in any preceding claim wherein the acoustic waves are acoustic compression waves.
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5. A data transmission as claimed in any preceding claim where the element is a continuous metal pipe.
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6. A data transmission system as claimed in claim 5 where the metal pipe is down a borehole and the first and second points are inside and outside the borehole respectively.

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Fig 1

