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(54) **Method and device for detecting pressure pulses.**

(57) A method of detecting mud pulses in a flowing stream of mud comprises monitoring the pressure change as the pulse-containing stream passes between two regions of the conduit of different cross-sectional area. A device for use in such a method comprises a body (12) defining a through bore for passing drilling mud therethrough, first and second regions in the bore, the second region having a greater cross-sectional area than the first, and means (18) for sensing the difference in pressure between the mud in the first and second regions.

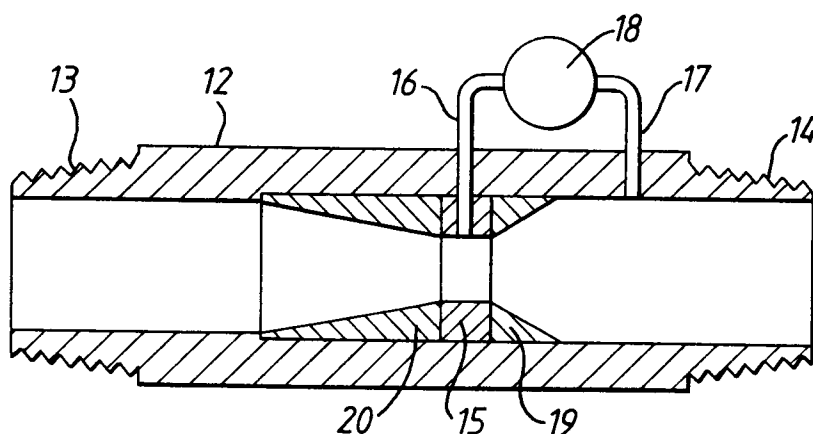


Fig. 4

This invention relates to a method and apparatus for detecting a pressure pulse in a flowing mud stream, and is particularly useful in measurement while drilling processes.

Measurement while drilling (MWD) is a technique whereby data collected at the bottom of a borehole are transmitted to the surface by some form of telemetry. This results in a major reduction in drilling time compared to other techniques in which drilling has to be stopped to permit instrumentation to be lowered down the hole on a wireline.

MWD is widely used in drilling for oil and gas. Parameters measured include direction and inclination of the drill string, and geological data such as gamma radiation, resistivity, porosity and density. Various telemetry methods have been tried, the most widely used at present being mud pulse transmission.

Drilling for oil and gas is carried out by means of a string of drill pipes, at the downhole end of which is the drill bit. The pipes are rotated either by a drive device on the surface or by a downhole motor or turbine. Drilling mud is pumped at high pressure down the drill pipes to emerge through jets in the bit. The mud then travels back up the hole via the annulus between the drillpipe and the hole wall, to be cleaned and recirculated. The functions of the drilling mud are to lubricate the bit, carry the cuttings back up to the surface, and balance the hydrostatic pressure in the rock formation.

Mud is pumped downhole by a positive displacement pump, usually with three cylinders. The pump pressure is up to 3000 psi (20.7 MPa) and the flow rate up to 1400 US gallons (5.3m³) per minute. The pumps can develop several hundred horsepower. (1hp is 746W.) A hydraulic accumulator, generally referred to as a de-surger in this application, is installed in the pipeline to absorb the pressure fluctuations from the pump. These would otherwise cause undue noise and vibration. The de-surger consists of a pressure vessel in which an elastomeric diaphragm separates a volume of nitrogen from the mud which fills the rest of the vessel. As will be seen, the de-surger affects the efficiency of mud pulse transmission.

Mud pulses can be generated by opening and closing a valve between the drillpipe and the annulus near the bottom of the drill string. When the valve is open, the pressure drop across the bit jets is bypassed to some extent, and the pressure in the drill pipe is reduced. A device operating in this way is generally referred to as a negative pulser. Alternatively, a valve in the drill pipe can be partially closed, causing a pressure increase or positive pulse. A third type of device produces a train of pulses which are phase modulated to transmit data. This is really a special case of a positive pulser.

Whatever type of pulser is employed, detection of the pulses is a major problem due to attenuation of the signal and the presence of noise from the pump and elsewhere. The signal to noise ratio is typically less than unity, necessitating the use of sophisticated electronic signal processing techniques to improve detection. Even with these, detection can be unreliable or impossible in some circumstances.

British patent specification no. 2160565A describes a way of overcoming at least some of these problems. According to this specification, the mud flow rate, rather than the mud pressure, is monitored at the surface using a flow meter downstream of the de-surger. The mud flow rate at the surface responds more sharply to a downhole mud pulse than does mud pressure and, in addition, signal to noise ratios for mud flow rate are much higher than for mud pressure. According to GB 2160565A, suitable flow meters are magnetic flow meters such as the Foxboro Series 2800 magnetic flowmeters manufactured by The Foxboro, Massachusetts, USA. Other types of commercially available flow meters, such as insertion type flow meters, can also be employed. Magnetic flow meters operate by establishing a magnetic field through which the slightly conductive drilling mud flows, thereby creating an electric potential. This potential, which is proportional to the rate of flow, is measured and electronically amplified and then transmitted to a recorder or data processor.

As a result of our own investigations, we also have found that surface measurement of mud flow instead of mud pressure gives a number of advantages. However, the use of sophisticated flow meters as envisaged in GB 2160565 is in itself disadvantageous since they are expensive and can be costly to install and use.

We have now found that the use of these flow meters is unnecessary, and that good results can be obtained by a different technique which does not necessitate the use of such sophisticated and expensive equipment.

It is an object of the invention to provide a new, effective and simple method of detecting mud pulses in a flowing stream of mud contained in a conduit.

According to one aspect of the present invention, mud pulses can be detected in a flowing stream of mud in a conduit by monitoring the pressure change as the pulse-containing stream passes between two regions of the conduit of different cross-sectional area. In accordance with this aspect of the invention, the flowing mud will show a pressure change as it passes from one region to the other. This difference in pressure will change as a mud pulse flows into one of the regions. This change in the difference in pressure between the two regions can be used very effectively to detect mud pulses in the mud stream.

It is thus possible, by the present invention, to provide very effective and low cost surface detection of mud pulses generated downhole while drilling. Apart from the simplicity and lower cost overall, the method of

the invention has other advantages too. For example, because it monitors the difference in pressure between the two regions, the background "noise" is of very little importance or effect. Furthermore, the change in pressure due to the arrival of a pulse in one region can be a greater percentage of the normal pressure difference between the regions, than is the change in flow rate with the GB 2160565 arrangement or the pressure change in conventional prior art procedures. These features give the present invention greater sensitivity and accuracy as compared with prior art procedures.

In accordance with the invention, the two regions of different cross-sectional area are preferably adjacent so that mud flows directly from one region into the other. The pressure in each region can be measured independently, and then compared (normally electronically) with the pressure in the other region. Alternatively, a differential pressure transducer can be connected to the two regions to give direct information as to the pressure difference.

In one highly preferred arrangement, a bypass conduit is tapped into a main conduit, and a venturi for example is provided in the bypass conduit, the pressure changes being measured in the bypass conduit this avoids having to interfere significantly with the main mud flow conduit on site (which can be difficult on a working drilling rig).

The invention also includes apparatus for detecting pulses in a stream of flowing mud, which comprises a body for connection into the mud flow path, a through bore in the body, the bore being of smaller cross-sectional area in the first region than in a second region, and means for sensing the difference in pressure between mud in the two regions.

Other objects and advantages of the invention will become apparent from the following specification taken in conjunction with the accompanying drawings.

Figure 1 is a simplified schematic view of a drill string mud circuit;

Figure 2 is a diagram depicting a mud pulse in the circuit;

Figure 3 is a schematic view of one arrangement in accordance with the present invention;

Figure 4 is a schematic cross-sectional view of one embodiment of an apparatus of the invention;

Figure 5 is a trace of pulse detections made by conventional processes (A) and by the method of the invention (B);

Figure 6 is a schematic cross-sectional view of an alternative embodiment of an apparatus of the invention; and

Figure 7 is a schematic plan view of another embodiment of apparatus according to the invention.

Referring to the drawings, a simplified mud circuit is shown in Figure 1. A mud pump 1 drives mud through a drill string 2. A de-surger 3 contains a diaphragm 4 and a volume of gas 5. A pressure transducer 6 is fitted downstream of the de-surger. The mud pulser is represented by a valve 7 and the bit jets by a restriction 8.

The pulser 7 effectively has two settings, one of which will create a higher pressure drop across the pulser than the other. The following discussion will relate to a positive pulser i.e. the pressure upstream will rise when a pulse is created. The invention is however equally effective with a negative pulser.

When the pulser is activated, the pressure immediately upstream increases and the velocity decreases. These changes do not occur instantaneously throughout the drill string, but propagate along it at the speed of sound in the fluid - approximately 4000 feet (1219m) per second. If the pressure transducer is 8000 feet (2438m) from the pulser, its reading will remain unchanged for two seconds after the pulser is activated.

The volume of mud produced by the pump can be assumed to be substantially unaffected by the increased pressure of the pulser signal. If the pulse were of sufficient duration for transients to die away, pressure at the transducer would stabilise at a higher value determined by the various losses in the system including the pulser restriction, and velocity at the transducer would return to its previous value.

In practice, the pulse is too short for stabilisation to occur, and the transient signal must be detected. This can best be visualised as a region in the drill pipe in which mud pressure is increased and velocity decreased. This is shown diagrammatically in Figure 2.

The region 9, which will be referred to as the pulse, moves upstream at the velocity of sound in the fluid. At the leading edge of the pulse there will be a transition area 10 in which the transition between lower pressure/higher velocity and higher pressure/lower velocity will occur. The length of the transition area will depend on the speed of operation of the pulser, the degree of diffraction due to changes in drill pipe section, and the effects of viscous friction. Similarly, there will be a second transition area 11 at the trailing edge of the pulse in which the opposite changes in pressure and velocity take place.

When the leading edge of the pulse 9 reaches the pressure transducer 6, an increase in pressure will be detected. However, when the leading edge reaches the desurger 3 the pressure will immediately be reduced to its previous value. This reduction in pressure will be reflected back down the drill pipe. When it passes the transducer, the indicated pressure will return to its normal value. The transducer will therefore register a short duration signal whose duration is twice the distance between the transducer and the de-surger divided by the

speed of sound in the fluid. These short duration signals are usually referred to as 'sonics', and are not always detected in practice.

The velocity of the fluid in the pulse is not similarly cancelled out by the presence of the de-surger. The reduced pressure at the upstream end of the pulse results in a further reduction in velocity, so while the pressure component in the pulse is removed, the velocity component is enhanced.

In practice, a pressure signal may still be detected in the absence of sonics, but its amplitude depends on the duration of the pulse. This can be illustrated by a numerical example:

Suppose a pump is supplying 300 US gallons per minute at a pressure of 1500 psi, and that a mud pulser at the bottom of the drill string can create an additional pressure drop of 200 psi. Total pressure difference when the pulser is activated is therefore $1500 + 200 = 1700$ psi.

Assuming a drill pipe bore above the pulser of 3.5 inches, cross sectional area is $3.5^2 \times \pi / 4 / 144 = 0.067$ square feet.

$$1 \text{ US gallon} = 0.134 \text{ cubic feet.}$$

$$\text{Velocity} = 300 \times 0.134 / 60 / 0.067 = 10 \text{ ft/second.}$$

Assuming that the change in velocity is proportional to the square root of the change in pressure difference:

$$\text{Velocity in the pulse} = 10 \times (1500/1700) = 9.4 \text{ ft/second.}$$

When the pulse reaches the de-surger, there is going to be a surplus of mud produced by the pump over that going downhole, proportional to the ratio of the two velocities. That surplus can only go into the de-surger.

The initial flow into the de-surger is:

$$\begin{aligned} 300 - 300 \times 9.4/10 &= 18 \text{ gallons per minute} \\ &= 0.3 \text{ gallons per second.} \end{aligned}$$

Assuming that the initial charge of gas in the de-surger is equivalent to a volume of 11 gallons at 1500 psi, the volume would reduce in one second to $11 - 0.3 = 10.7$ gallons.

The pressure in the de-surger would increase to:

$$1500 \times 11/10.7 = 1542 \text{ psi.}$$

The initial rate of pressure change is only 42 psi per second. A pulse of 0.1 seconds duration would only give a pressure rise, sonics apart, of 4.2 psi. This would be extremely hard, if not impossible to detect.

It can be seen from the foregoing that it would be preferable to detect the velocity component of a pulse rather than the pressure component. The invention to be described provides a method of doing this.

Figure 3 shows two pressure transducers 30, 31 installed in sections 32, 33 of pipe having different diameters. Since the sum of pressures and kinetic energies remains constant, the pressure in the smaller diameter pipe will be lower. This effect is well known in fluid mechanics and can be expressed as:

$$P_1 - P_2 = (V_2^2 - V_1^2) \times D / 2 / 144 / 32.2$$

Where:

P1 = pressure in the larger diameter

P2 = pressure in the smaller diameter

V1 = velocity in the larger diameter

V2 = velocity in the smaller diameter

D = density in pounds per cubic foot

144 = square inches/square foot

32.2 = acceleration due to gravity ft/sec²

Taking density as 78 pounds per cubic foot, assuming a reduction in pipe diameter from 3.5 to 2.5 inches, and taking the original value of 10 ft/sec for V1.

$$V_2 = 10 \times 3.5^2 / 2.5^2 = 19.6 \text{ ft/sec.}$$

$$P_1 - P_2 = (19.6^2 - 10^2) \times 78 / 2 / 144 / 32.2 = 2.4 \text{ psi.}$$

When V1 reduces to 9.4 ft/sec due to the arrival of a pulse,

$$V_2 = 9.4 \times 3.5^2 / 2.5^2 = 18.4 \text{ ft/sec}$$

$$P_1 - P_2 = (19.4^2 - 9.4^2) \times 78 / 2 / 144 / 32.2 = 2.1 \text{ psi.}$$

If the signals from the two transducers are subtracted electrically, the remaining difference signal will give an accurate indication of velocity. Alternatively, a differential pressure transducer may be connected between the two pressure tappings to give a direct indication of velocity.

The distance between pressure tappings should be kept to a minimum for optimum detection of short pulses. Figure 4 shows a device designed for mud pulse velocity detection. It consists of a body 12 preferably having screw threads 13, 14 at each end to permit fitting in the pipeline from the de-surger to the drill pipe. The body

has an internal constriction 15 with a pressure tapping 16. A second tapping 17 is provided in the larger diameter of the body. A differential pressure transducer 18 is connected across the two tapings. The constriction may optionally be faired by two tapered sections 19, 20 to reduce erosion due to turbulent mud flow.

As an additional refinement, the cross sectional area at the constriction may be adjustable by means of a plunger operated by a screw thread or hydraulic ram in order to accommodate the range of mud flow rates encountered in practice.

Figure 5 is an example of unprocessed pressure (A) and velocity (B) traces obtained from a positive pulser at a depth of 4500 feet, using the detection device described above for velocity. The greater amplitude and clarity of the velocity signal are obvious. Pulse width is 0.5 seconds.

Figure 6 shows an alternative device for mud pulse velocity detection. The device as shown is adapted to fit into a standard pressure transducer tapping 40 which may already exist on rig pipework 41 by means of screw threads 42 in the tapping. Alternatively, the device may be provided within a screw-threaded body for fitting into a pipeline in a manner similar to that described with respect to the Figure 4 embodiment.

The device of Figure 6 comprises a plunger 43 slidably supported within a sleeve 44. The sleeve 44 is provided with screw threads 45 which cooperate with screw threads 42 in the tapping 40. A shoulder 46 on a plunger 43 separates a first portion 47 of the plunger from an end portion 48 of the plunger having a larger diameter than the first portion 47. The shoulder 46 limits the distance by which the plunger 43 is permitted to slide within the sleeve 44. An annular recess 49 is provided in the first portion 47 of the plunger and a screw-threaded hole 50 is provided in the sleeve 44. A locking screw 51 fits through the hole 50 and cooperates with the annular recess 49 to permit fixing of the plunger 43 within the sleeve at the correct depth and alignment, as will be described in more detail below. O-ring seals 60 are provided between the plunger and the sleeve to prevent leakage of the drilling mud from the pipework 41.

A high pressure tapping or aperture 52 is formed in the plunger 43, and is connected via a through-passage 53 and a connecting loop 54 with one side of a differential pressure transducer 55. A low pressure tapping or aperture 56 is also formed in the plunger 43, and is connected via a through-passage 57 and a connecting loop 58 with the other side of the differential pressure transducer 55. The low pressure aperture 56 is oriented at right angles to the high pressure aperture 52.

As shown in Figure 6, the drilling mud is flowing through the pipework 41 in the direction of arrow 59. In order to use the device of Figure 6 to detect mud pulse velocity, the device is positioned in the tapping 40 and the location of the plunger 43 within the sleeve 44 is adjusted, such that the end portion 48 of the plunger protrudes into the fluid flow by a selected amount in order to cause a restriction in the flow. The plunger is oriented with the high pressure aperture 52 facing upstream, as shown, and the depth and orientation of the plunger are set by means of the locking screw 51.

In the position shown in Figure 6, the high pressure aperture 52 is exposed to the stagnation pressure in the flow, since the restriction in the flow caused by the end portion 48 of the plunger 43 creates a stagnation point immediately upstream of the plunger. The low pressure aperture 56 is exposed to the static pressure of the fluid near the minimum cross-section of the restriction in the flow.

The sensitivity of the device of Figure 6 is therefore higher than that of the device of Figure 4 since it senses the high pressure at a stagnation point in the flow.

A further advantage of the device shown in Figure 6 is that it can be fitted to the standard transducer tapings already provided on rig pipework, thus facilitating installation.

The end portion 48 of the plunger 43 may be provided with a streamlined shape, or with an aerofoil.

In the embodiment of Figure 7, a main mud flow conduit 70 (the direction of flow being shown by arrow 71) is tapped to provide a bypass passage 72 in parallel to the main flow 71. A venturi 73 is provided in the bypass and a pressure sensor 74 is provided connected at one side to the venturi and at the other side upstream of the venturi. This arrangement enables the invention to be used without carrying out major interfering work on the main flow conduit 70.

It must be understood that the foregoing description has been given only by way of example and that it in no way limits the scope of the invention. Clearly various modifications and changes may be made by those skilled in the art without departing from the spirit and scope of the invention.

Claims

1. A method of detecting mud pulses in a flowing stream of mud in a conduit comprising comparing pressure signals from two regions of the conduit of different cross sectional area.
2. A method according to Claim 1, wherein the pressure signal from each of the two regions is measured

independently, and the pressure signals are then compared.

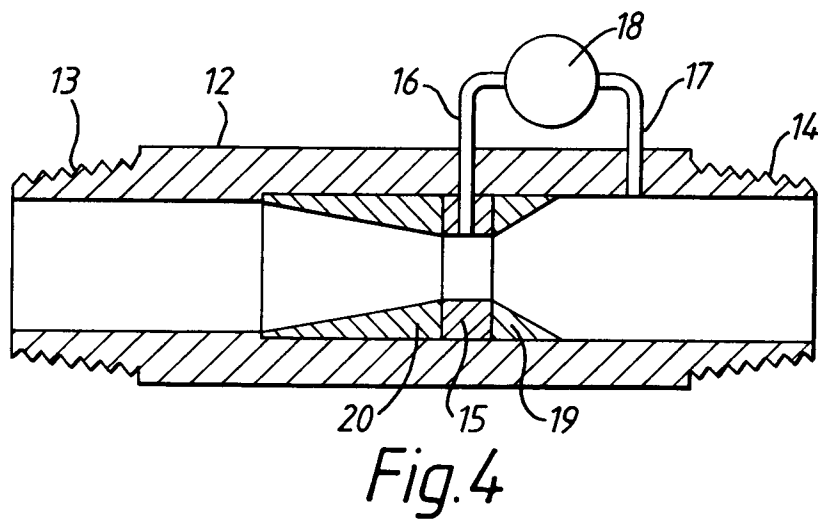
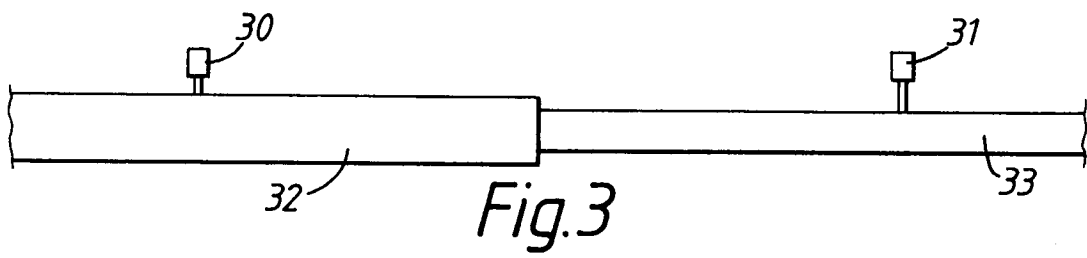
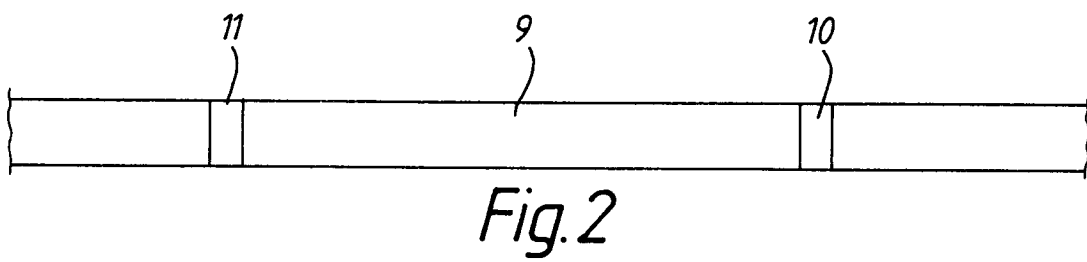
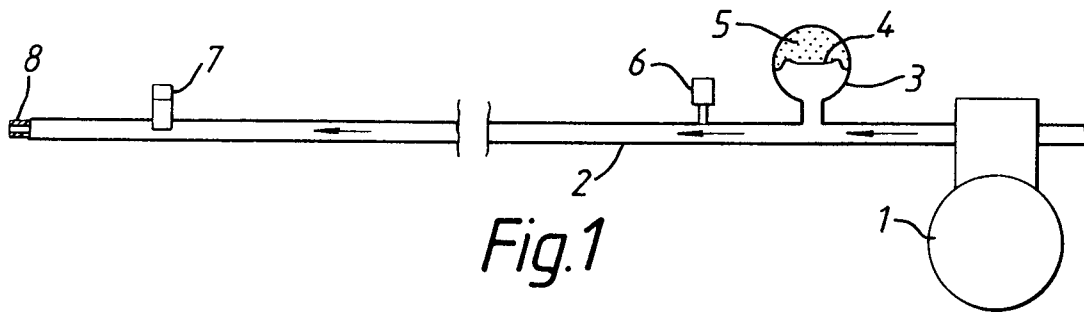
3. A method according to Claim 1 or 2, wherein a differential pressure transducer is connected to the two regions and a direct comparison of the pressure signals is provided.
- 5 4. A method according to Claim 1,2 or 3, wherein the two regions are adjacent.
5. A method according to Claim 1,2,3 or 4, wherein the stream of mud is in a bypass parallel to a main mud flow conduit.
- 10 6. A mud pulse detection device comprising a body (12) defining a through bore for passing drilling mud therethrough; a first region in the bore; a second region in the bore having a greater cross-sectional area than said first region; and means (18) for sensing the difference in pressure between the mud in the first and second regions.
- 15 7. A mud pulse detection device according to Claim 6, wherein means (13,14) are provided on said body for connection of said body (12) in a drilling mud circuit.
8. A mud pulse detection device according to Claim 6 or 7, wherein said first region is provided by an internal constriction (15), and wherein said device additionally comprises a first pressure tapping (16) exposed to pressure in the first region, a second pressure tapping (17) exposed to pressure in the second region, and a means for measuring and transmitting the difference in pressure between the first and second tap-
20 pings.
9. A mud pulse detection device according to Claim 8, wherein streamlined fairings (19,20) are provided on the constriction (15).
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10. A mud pulse detection device according to Claim 8 or 9, wherein the cross-sectional area at the constriction (15) is adjustable by means of a plunger.
- 30 11. A mud pulse detection device according to Claim 10, wherein the plunger is operable by means of a locking screw.
12. A mud pulse detection device according to Claim 10, wherein said first and second pressure tapplings are provided within the plunger, and wherein said second pressure tapping is exposed to the pressure at a stagnation point upstream of said plunger.
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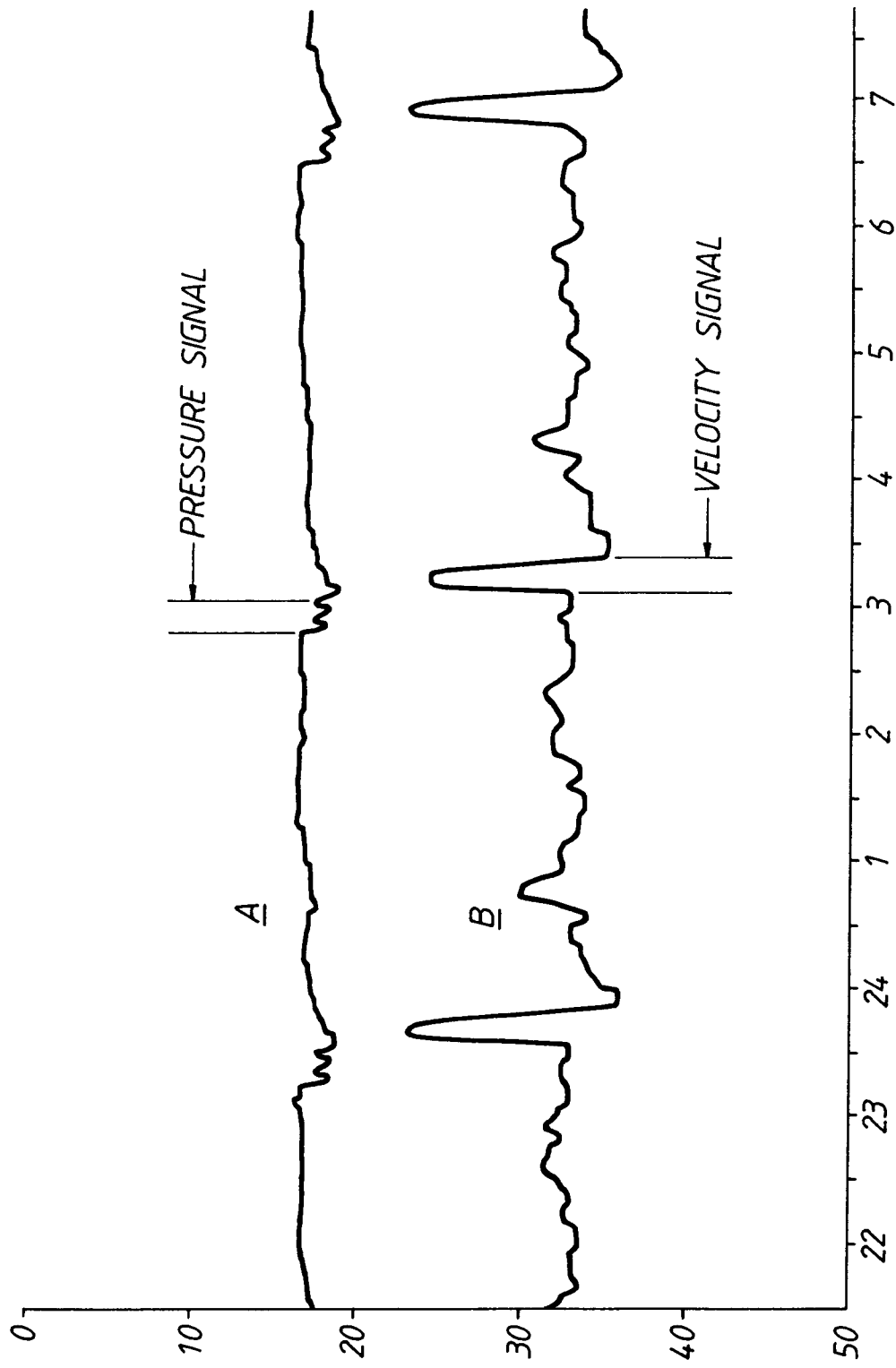
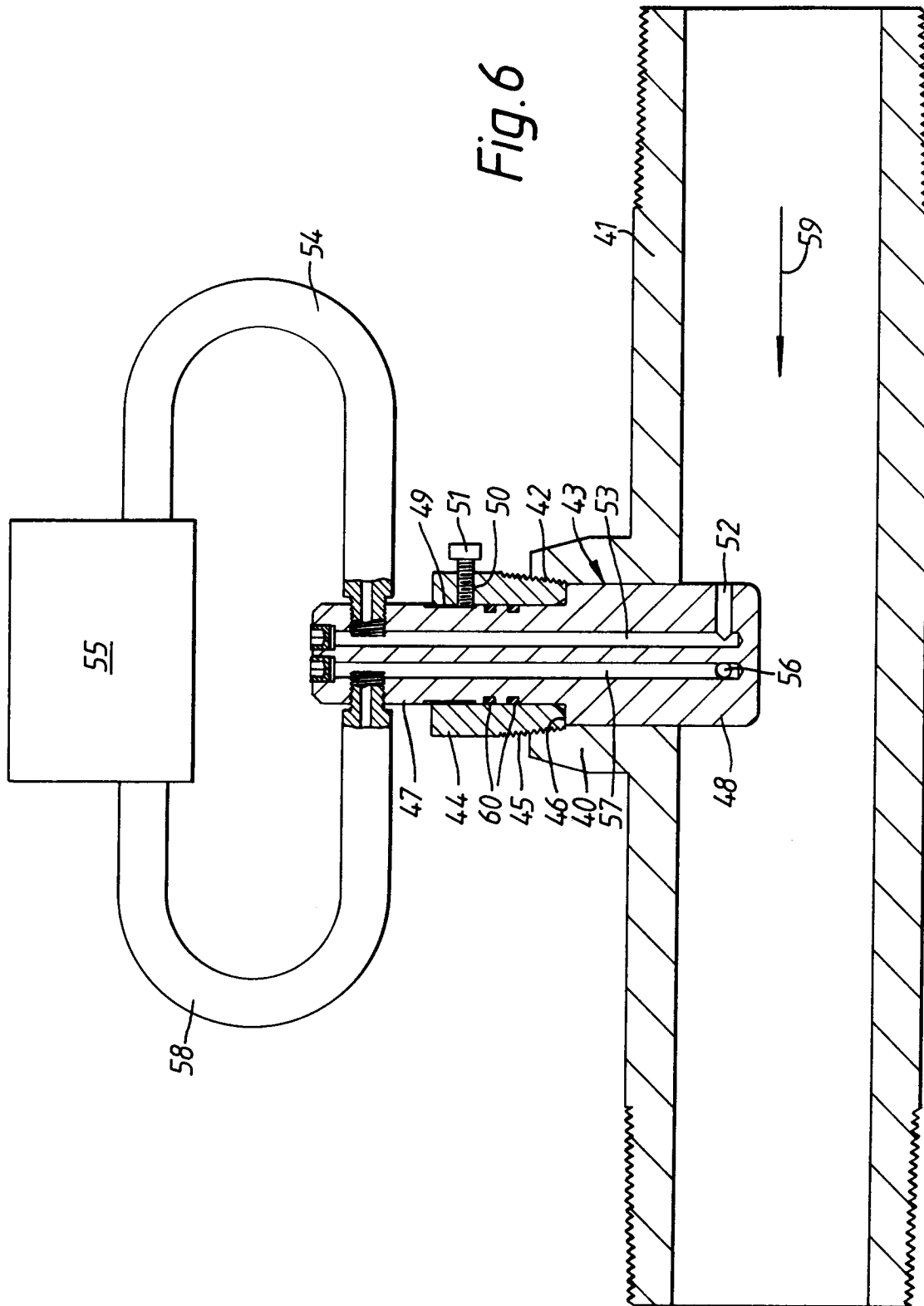


Fig.5



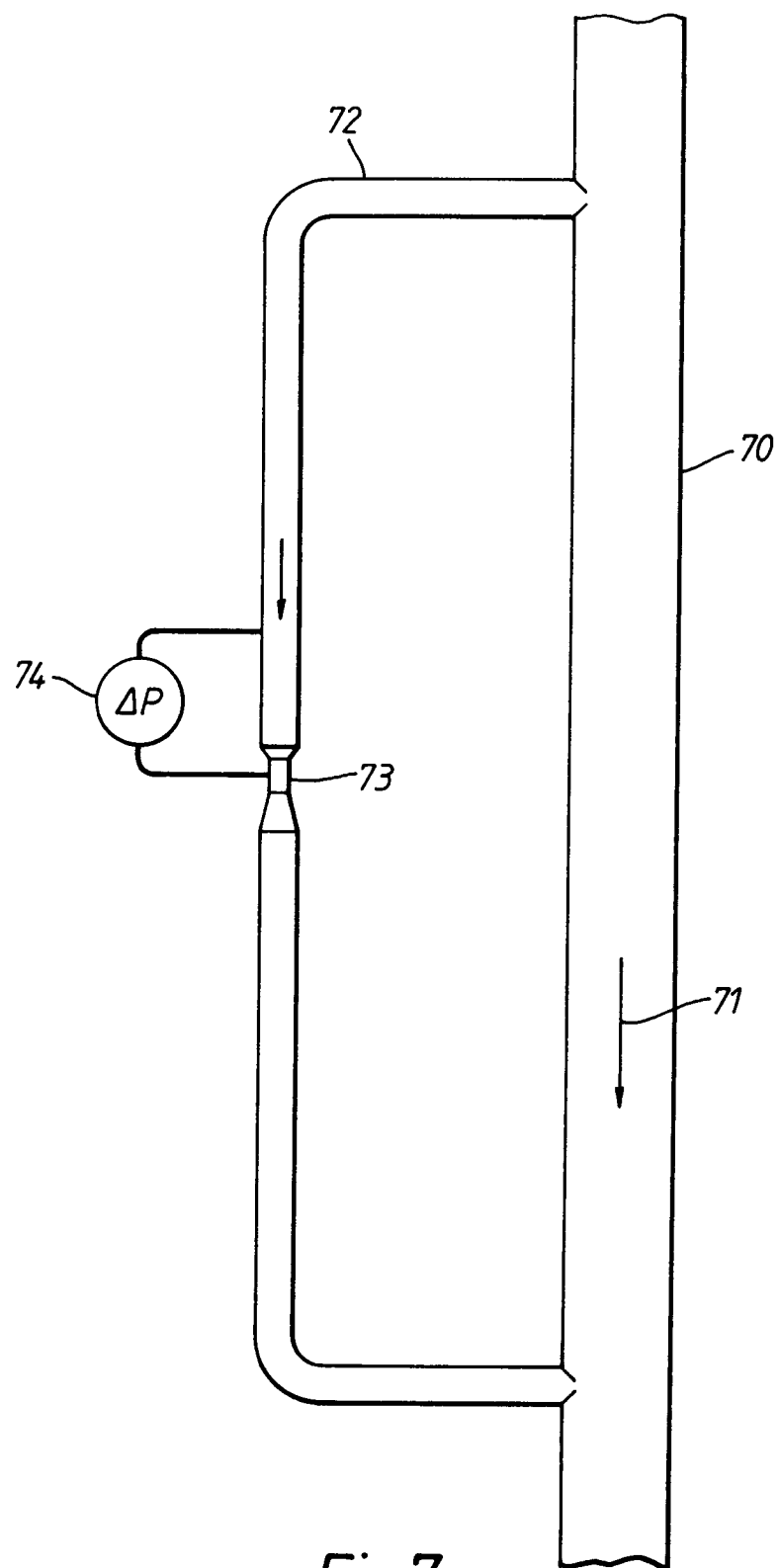


Fig.7