(12) UK Patent Application (19) GB (11) 2 209 217 (13) A

(43) Date of A publication 04.05.1989

(21) Application No 8720342.8

(22) Date of filing 28.08.1987

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(51) INT CL⁴
G01F 1/66

(52) UK CL (Edition J)
G1G GPKT

(56) Documents cited
GB 2026165 A US 4610167 A
GB 2026165 A is equivalent to US 4320666 A

(58) Field of search
UK CL (Edition J) G1G GPKD GPKT GPKX
INT CL⁴ G01F

(54) **An ultrasonic fluid flow meter**

(57) In order to make an ultrasonic flow meter more compact, reflecting surfaces 2*b*, 2*c* are provided so that ultrasonic signals from transducers 4, 5 travel along a region 2*a* of the flow path 2 substantially parallel to the axis of that region. A guide 10 may be provided to suppress off-axis modes along that region. Times of flight may be measured by varying the frequency to maintaining constant phase shift upstream and downstream. The timing circuit is also disclosed.

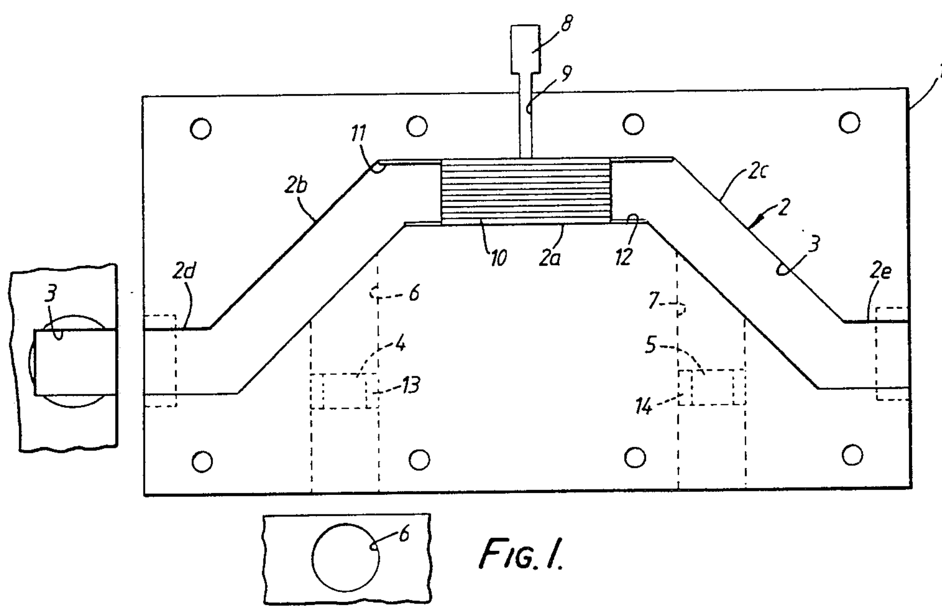

FIG. I.

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy

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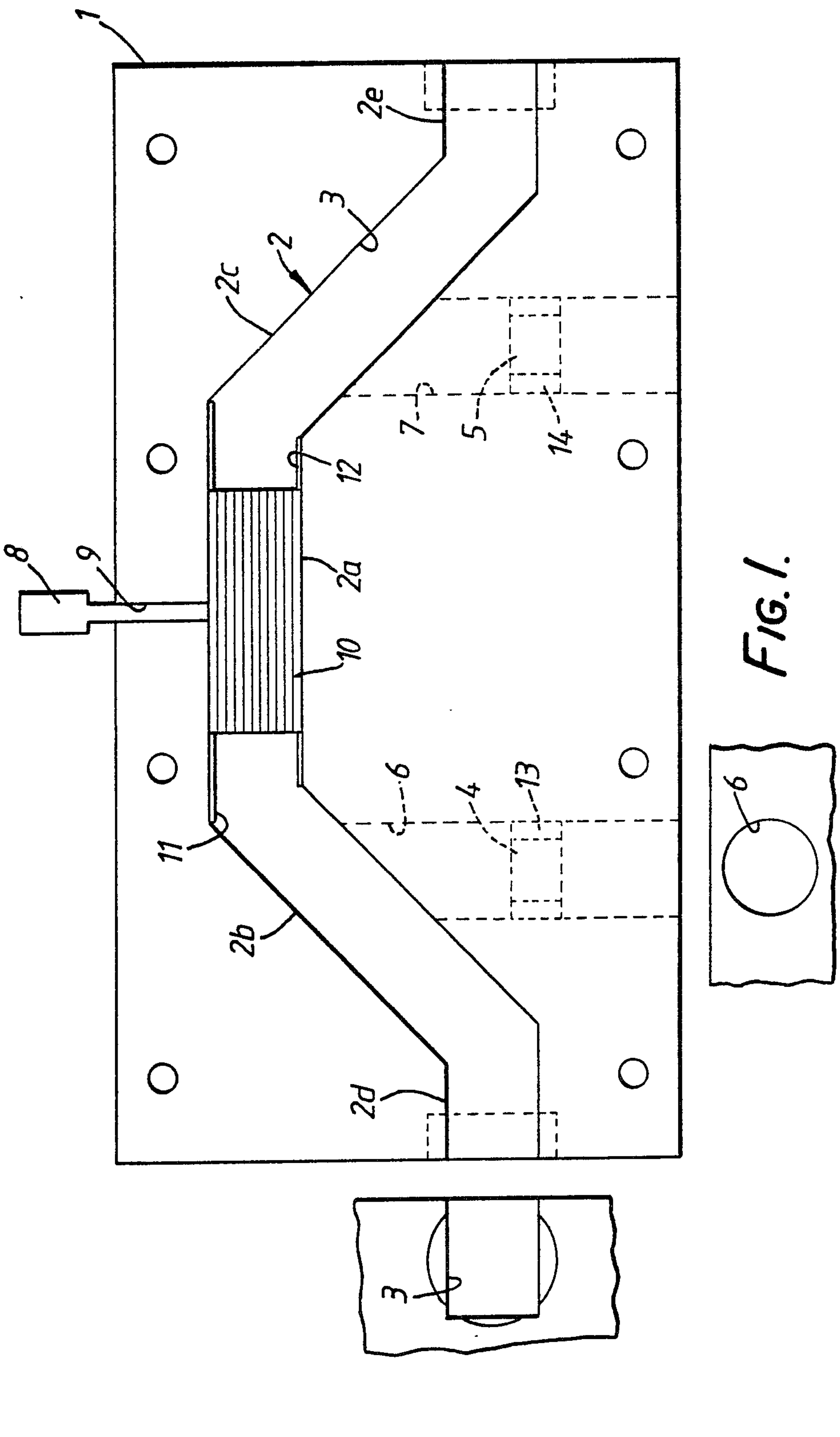

FIG. 1.

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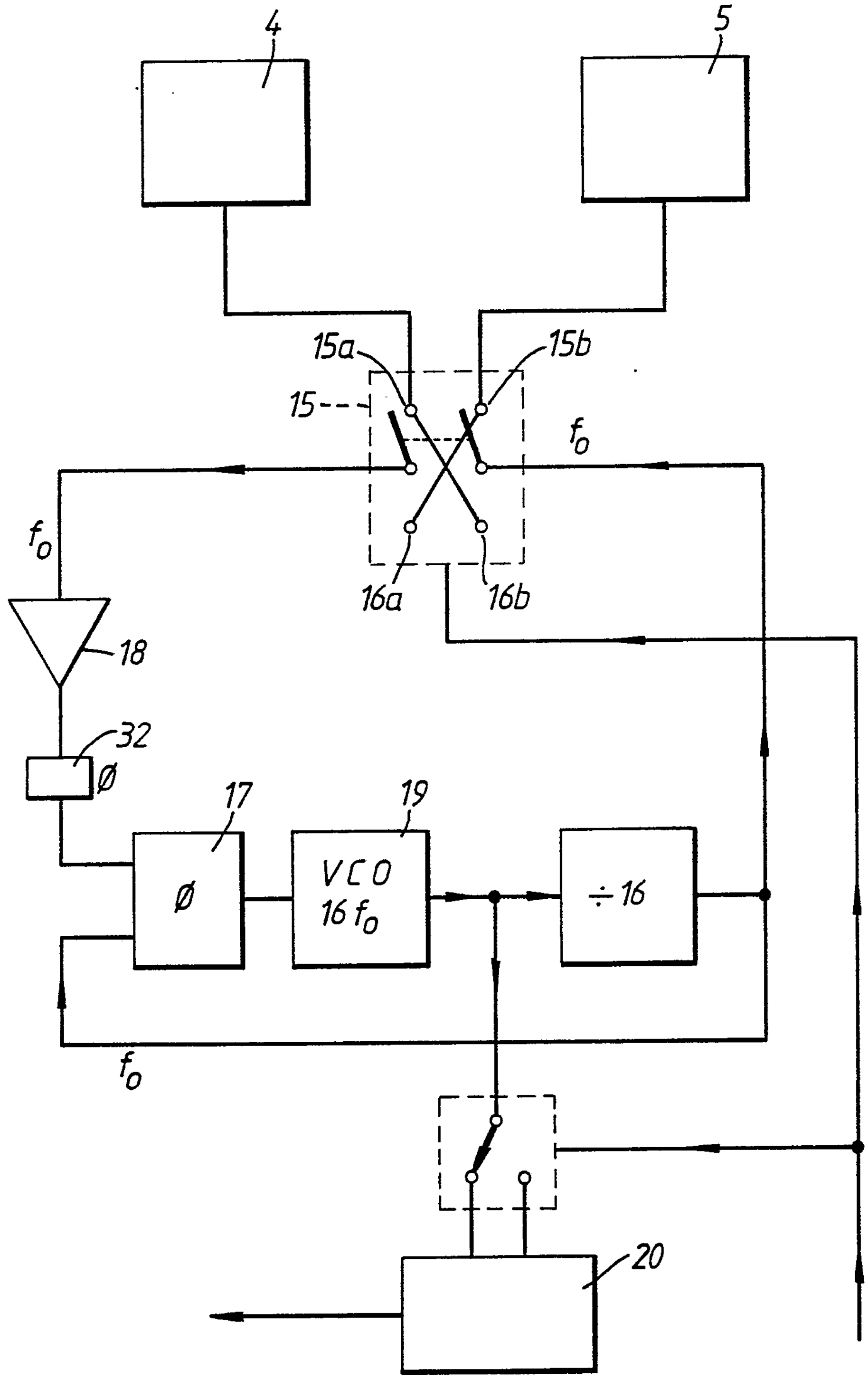

FIG. 2.

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Flow-meter for sensing the velocity of flow of a fluid

This invention relates to flow-meters for sensing the velocity of flow of a fluid.

It is known to employ a pair of ultrasonic transducers obliquely arranged across a flow path, where each transducer can transmit to and receive from the other, and to obtain the measure of the flow velocity from the difference in the "time of flight" of the ultrasonic signals travelling upstream and downstream. However, it is difficult to make such an arrangement compact.

The invention provides a flow meter for sensing the velocity of flow of a fluid, comprising means defining a flow path for the fluid, a pair of ultrasonic transducers arranged so that a signal transmitted by each will be received by the other, and one or more reflecting surfaces arranged so that, over part of their paths, the ultrasonic signals travel along a region of the flow path substantially parallel to the axis of that region of the flow path.

Since part of the path of the ultrasonic signal is parallel to the axis of the associated region of the flow path, it is possible to make the meter more compact.

Advantageously, the transducers are mounted in passages which extend from the flow path and, preferably, the reflecting surfaces are formed by walls of the flow path adjacent to the region along which the signals travel substantially parallel to the axis. With such an arrangement the transducers can all be clear of the flow path, and the restriction of flow produced by the flow-meter can be small.

Guide means may be provided in the region of the flow path along which the ultrasonic signals travel substantially axially, in order to suppress other possible flow paths.

The time difference of the ultrasonic signals upstream and downstream is advantageously measured in terms of frequency, in order to provide a signal which can interface with digital electronics.

The flow-meter may be used in conjunction with a pressure sensor for determining the mass flow rate of a fluid, since the density on the fluid is related to the pressure.

A flow-meter for a gas constructed in accordance with the invention will now be described by way of example with reference to the accompanying drawings, in which:

Fig. 1 is a plan view of the flow-meter showing the shape of the flow path;

Fig. 2 is a block diagram of an electric circuit for the velocity sensing transducers;

Referring to figure 1, the flow-meter is formed in a metal block 1. A gas flow path 2 is defined by a slot 3 of rectangular cross-section which is machined into the top surface of the block and closed by a cover (not shown) which is bolted to the block. Transducers 4,5 capable of emitting as well as receiving ultra-sonic vibrations are mounted in passages 6,7 which communicate with the gas flow path, and signals derived from these transducers give a measure of the velocity of gas flow along the path 2 as well as a measure of the velocity of the acoustic waves in the gas.

The flow path 2 includes a region 2a along which the ultra-sonic waves travel axially. In the interests of keeping the overall length of the block 1 to a minimum, the passages 6,7 housing the velocity measuring transducers 4,5 are orientated at right angles to the region 2a, and the ultra-sonic waves are reflected by surfaces inclined at 45° between the region 2a and the passages 6,7.

The reflecting surfaces are formed by the walls of the regions 2b, 2c, the axes of which are inclined at 45° to the axis of the region 2a. The inclined regions 2b, 2c thus provide the necessary deflection of the ultra-sonic waves, but also do not provide any substantial impedence to gas flow. Short regions 2d,2e parallel to the region 2a form the inlet and outlet respectively of the flow meter.

The transducers 4,5, which are of identical form, emit and receive ultra-sonic waves in a cone-shaped region extending from the transducers. To prevent there being different possible path lengths between the transducers, a guide 10 for axial ultra-sonic waves only is positioned in the region 2a to suppress off-axis modes. The guide consists of an insert which has closely packed hexagonal channels extending throughout its length. The region 2a is lined with acoustic absorbing foam pads 11,12 at each end of the guide to suppress multiple reflections.

The transducers are supported in the passages 6,7 in plugs 13,14 of silicone rubber which block off the passages 6,7 and at the same time isolate the transducers from vibration.

The transducers 4,5 sense the velocity of gas flowing along the path 2 because a signal transmitted by one transducer and received by the other takes less time when it travels in the direction of gas flow than when it travels against the direction of gas flow, since the ultra-sonic signals are of course propogated in the gas itself.

The time of flight between transmitter and receiver can be conveniently measured in frequency form by coupling the transmitter and receiver together in a "sing-around" system, where the oscillation frequency stabilises at two values which maintain a fixed phase shift between transmitted and received signals. Thus, the respective times of propogation from transducer 4 to transducer 5 and vice-versa are measured by varying for each direction of propogation the driving frequency until exactly the same number of wavelengths, not necessary an intregal number, exists between the transmitting transducer and the receiving transducer, and this is done by producing a pre-determined phase difference, for example, zero, between the transmitted signal and the received signal. The difference between these two frequencies is proportional to the velocity of gas along the flow path and the sum of these two frequencies is proportional to the velocity of the ultra-sonic waves in the gas.

Thus, if one assumes that the component of path along the flow path axis between the transmitter and the receiver is L and the acoustic velocity in the gas is C, with a mean flow velocity V averaged over the flow path diameter, the time taken for sound at frequency f_1 to propogate between the transducers <u>in</u> the flow direction is t_1, where

$$t_1 = \frac{L}{C + V}$$

If the sing-around frequency is f_1 the phase shift along the acoustic path is proportional to the product f_1 t_1 which is maintained at a fixed value N by the sing-around system.

Thus,

$$f_1 = \frac{N}{t_1} = \frac{N}{L} \quad (C + V)$$

If the transducers are now interchanged so that sound propogates <u>against</u> flow, sing-around frequency f_2 is given by

$$f_2 = \frac{N(C - V)}{L}$$

The difference in frequencies $f_1 - f_2$ is therefore

$$\Delta f = f_1 - f_2 = \frac{2N V}{L}$$

The sum of the frequencies is $fo = f_1 + f_2 = \frac{2NC}{L}$

The difference in frequency therefore gives a measure of the flow velocity and the sum gives a measure of the acoustic velocity in the gas. The difference frequency therefore provides a measure of volume flow rate which is independent of the speed of sound ~~physical characteristics~~ of the gas.

The differencing technique allows a wide range of flow velocities to be covered without making impossible demands on the stability of operating conditions to achieve the necessary accuracy at low velocity at the low velocity end of the range.

Referring to figure 2, electronic analogue gate cross-over switch 15 switches over every ½ a second between states connecting contacts 15a, 15b and 16a, 16b together. In the first position, the transducer 5 is driven and the transducer 4 receives. The signal is fed to a phase detector 17 via an operational amplifier 18 which amplifies the signal until it is comparable with the signal fed to the transducer 5 which is directly fed back to the phase detector. The output of the phase detector 17 controls a voltage controlled oscillator 19 which varies the frequency of its output until there is a predetermined phase difference, for example, 0°, between the two inputs to the phase detector. The same procedure happens when the contacts 16a,16b are connected together and a ~~difference~~ frequency corresponding to the fixed phase difference for propogation <u>with</u> the gas flow is locked onto.

The frequency corresponding to zero flow is chosen in relation to the distance between the transmitter and receiver to ensure that the phase differences introduced when alternating between the two states are sufficiently small that the phase locked loop locks onto the same number of wavelengths between transmitter and receiver for the range of flow velocities to be measured in each case and cannot lock onto a larger or smaller number of wavelengths.

In order to subtract one frequency from the other, a counter 20 counts up from zero during one ½ second period and then, during the second ½ second period, counts down from the number reached. The difference between the two counts is proportional to the difference between the frequencies. To obtain a more accurate count, the output frequency of the voltage controlled oscillator is multiplied by a factor of 16 for feeding to the counter, to achieve sufficient velocity resolution at low flow rates, and then divided by a factor of 16 for feeding to the transducers and the phase detector.

As an example of suitable dimensions and operating frequencies, the length of the section 2a may be approximately 80mm and the cross-section of the passage may be approximately 20mm by 20mm. The transducers 4,5 may each consist of an 8mm diameter piezo-electric ceramic disc with a small aluminium cone attached to the centre to act as a radiator. A few volts applied to the transducers at the resonance frequency generates sound pressure levels of 100dB a few centimetres from the transmitting aperture.

When used as receivers, the transducers generate output voltage at the order of 0.1 to 1 volt when placed a few centimetres away from the transmitter. The transducers have resonance bandwidths centred on 40kHz of approximately 2kHz. With this example, four complete wavelengths can be accommodated between transmitter and receiver in each direction of propogation of the ultrasonic waves. A flow rate of approximately 3 metres/second would on this basis produce a difference frequency of approximately 800Hz.

Variations are of course possible. Thus, the section 2a could be from 60mm to 100mm long, the flow path diameter could be from 10mm to 40mm, the centre frequency of the transducer 4,5 could be from 30kHz to 100kHz, and the response curve against frequency for amplitude and phase should be as flat as possible.

Equally, the regions 2b,2c could lie at different angles to region 2a, passages 6,7 being appropriately re-orientated to receive the reflected signals.

As an alternative to piezo-electric materials, multiple layer PVDF could be used, or bulk ceramic transducers using acoustic matching layers could be used.

Although the flow-meter is for sensing the velocity of flow of a gas, it could be combined with a pressure sensor to form a mass flow-meter, since the pressure gives a measure of the gas density.

Further, the flow-meter could be used for sensing the velocity of flow of any fluid, that is, other gases or liquids.

Co-pending application no. 8720341 is directed to a mass flow-meter which may include the velocity flow-meter of Figures 1 and 2, application no. 8720343 is directed to an anti-fraud device described with reference to Figure 2, and application no. 8720344 is directed to a pressure sensor.

CLAIMS

1. A flow meter for sensing the velocity of flow of a fluid, comprising means defining a flow path for the fluid, a pair of ultra-sonic transducers arranged so that a signal transmitted by each will be received by the other, and one or more reflecting surfaces arranged so that, over part of their paths, the ultra-sonic signals travel along a region of the flow path substantially parallel to the axis of that region the flow path.

2. A flow meter as claimed in claim 1, in which the transducers are mounted in passages which extend from the flow path.

3. A flow meter as claimed in claim 1 or claim 2, in which the reflecting surfaces are formed by walls of the flow path adjacent to the region along which the signals travel substantially parallel to the axis.

4. A flow meter as claimed in claim 3, in which the walls of the flow path which form the reflecting surfaces are each inclined at the same angle to the axis of the region of the flow path along which the signals travel substantially parallel to the axis.

5. A flow meter as claimed in claim 4, in which the angle of inclination is 45^{o}.

6. A flow meter as claimed in any one of claims 1 to 5, in which guide means is provided in the region of the flow path along which the ultra-sonic signals travel substantially axially, in order to suppress other possible flow paths.

7. A flow meter as claimed in any one of claims 1 to 6, in which the transducers are each mounted in resilient supports to isolate them from vibrations.

8. A flow meter as claimed in any one of claims 1 to 7, in which in use the transducers alternately transmit and receive, and means is provided to vary the frequency between transmission in the direction of flow and counter to the direction of flow in such a way that the number of wavelengths and the phase between the transmitted and received signals remains the same in each case.

9. A flow meter as claimed in claim 8, in which a counter is arranged to count in one direction during one direction of propogation and in the reverse direction during the opposite direction of propogation.

10. A flow meter as claimed in any one of claims 1 to 9, in which the flow path diameter lies in the region of from 10mm to 40mm.

11. A flow meter as claimed in any one of claims 1 to 10, in which the length of the region of the flow path along which the ultra-sonic signals travel substantially parallel to the axis lies between 60mm and 100mm.

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