



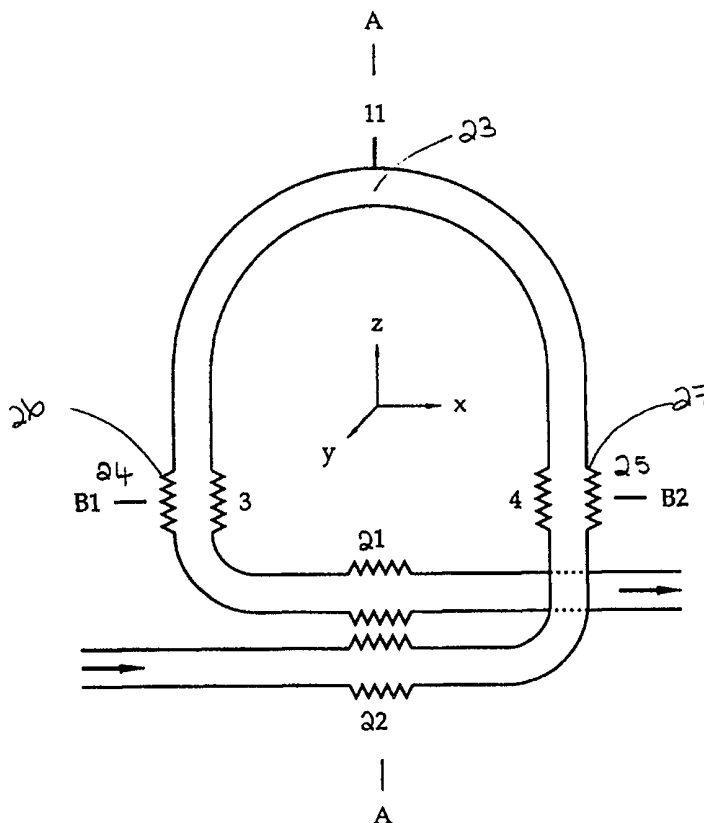
INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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<p>(21) International Application Number: PCT/NZ99/00103 (22) International Filing Date: 2 July 1999 (02.07.99) (30) Priority Data: 330856 2 July 1998 (02.07.98) NZ (71) Applicant (for all designated States except US): INDUSTRIAL RESEARCH LIMITED [NZ/NZ]; Gracefield Road, Lower Hutt (NZ). (72) Inventors; and (75) Inventors/Applicants (for US only): SUTTON, Christopher, Mannings [NZ/NZ]; 8 Crofton Road, Ngaio, Wellington (NZ). WHITE, David, Rodney [NZ/NZ]; 45 Normandale Road, Lower Hutt (NZ). (74) Agents: WEST-WALKER, Gregory, James et al.; Russell McVeagh West-Walker, Level 18, Mobil on the Park, 157 Lambton Quay, Wellington (NZ).</p>		<p>(81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).</p> <p>Published With international search report. Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</p>

(54) Title: A CORIOLIS EFFECT FLUID FLOW METER

(57) Abstract

A coriolis effect fluid flow meter comprises a tube curved about a first axis and mounted via flexible couplings for oscillatory motion about a second axis, means to drive the tube in a controlled oscillatory motion about said first axis to generate in fluid flowing in the tube a measurable bi-directional force, and means arranged to measure the bi-directional force in the direction of said first axis and to derive the fluid flow therefrom.



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A CORIOLIS EFFECT FLUID FLOW METER

FIELD OF INVENTION

5 This invention relates to apparatus for measuring the flow of a fluid mass.

In this specification the term "fluid" is intended to refer to any flowing substance whether it may be liquid or a gaseous or a polyphase substance such as a liquid/solid or a liquid/gas.

10

BACKGROUND OF INVENTION

Various methods are known for the measurement of the flow of a fluid mass and in particular it is known to use flow meters based on the Coriolis effect because they
15 are capable of measuring the mass flow directly and are relatively insensitive to the properties, such as density and viscosity, of the fluid being measured. However, one of the main disadvantages of flow meters based on the Coriolis effect measurement is because the Coriolis forces generated are generally very small, the measurements are subject to interference from effects which are difficult to
20 suppress.

Boom R J in "A User's Perspective for Coriolis Flow Meters" 44th Annual Symposium on Instrumentation for the Processes Industry 1989 referred on pages 7 - 10 to some patents granted in the 1950's for "gyroscopic mass flow meters". All of these
25 early meters involved curved members, a means of oscillation/vibration, and some sort of flexible coupling or slip joints and all attempted to measure the torque caused by the gyroscopic (Coriolis) effect. Such early gyroscopic meters were failures and all exhibited a common problem that because the Coriolis forces were small compared to other forces, then it was not possible to obtain accurate
30 readings.

US patent 3927565 describes an apparatus for measuring the mass flow of fluid and utilises a rectilinear pipe which can be rotated about an axis which is not parallel with the longitudinal axis of the pipe. The apparatus also includes a means for

making the fluid flow through the pipe and means for measuring the force which the fluid flowing through the pipe exerts on a segment of the pipe.

US patent 4109524 describes another method of measuring the mass flow rate 5 using the Coriolis effect and describes an apparatus which includes a conduit having sections. A section of one end of the conduit is reciprocated and the torque generated by the Coriolis force is measured.

US patent 4252028 describes an apparatus for measuring mass flow and utilises a 10 plurality of channels which are provided in one or more conduits which rotate or oscillate as a common unit. Additive streams flow to the channels in one direction and subtractive streams are flowed through the channels in the opposite direction and the Coriolis force thereby imposed on the conduit is measured.

15 **SUMMARY OF INVENTION**

The invention provides an improved or at least alternative form of Coriolis flow meter.

20 In broad terms in one aspect the invention comprises a flow meter based on the Coriolis effect comprising a substantially U shaped tube driven in a controlled oscillatory motion about an axis to generate in the fluid within the tube a measurable bi-directional force, said U tube including flexible couplings intermediate of the length of the tube and adapted to allow the tube to be oscillated 25 at a frequency which is not necessarily the resonant frequency of the tube.

In broad terms in another aspect the comprises a fluid flow meter based on the Coriolis effect comprising two U shaped tubes each including flexible couplings intermediate of their length and each being adapted to be excited by an oscillatory 30 motion in which the motion in one tube is 180° out of phase with the other tube and wherein the fluid flow through the tubes is in the same direction, means being provided to measure the difference in oscillatory force between the two tubes.

In broad terms in a further aspect the invention comprises a fluid flow meter based 35 on the Coriolis effect comprising two U shaped tubes each including flexible

couplings intermediate of their length and each being adapted to be excited by an oscillatory motion in which the motion in one tube is in phase with the other tube and wherein the fluid flow through the tubes is in the opposite direction, means being provided to measure the difference in oscillatory force between the two tubes.

5

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is described with reference to the accompanying drawings by way of example and without intending to be limiting, in which:

10

Figure 1 is a diagrammatic view of the basic principle of a Coriolis mass flow meter;

Figure 2 is a diagrammatic view of a known Coriolis flow meter which utilises the tubular arrangement as shown in Figure 1; and

15

Figure 3 is a diagrammatic view of a Coriolis flow meter of the present invention.

DETAILED DESCRIPTION

20 In the basic type of Coriolis flow meter as shown in Figure 1, fluid flows through the tube about the y axis and at the same time the tube is rotated about the x axis. The two motions will result in a torque about the z axis. The torque about the z axis is proportional to the mass flow rate through the tube.

25 Figure 2 illustrates a Coriolis mass flow meter utilising this basic principle. A single U tube 1 has an inlet 2 and an outlet 3 so that fluid can flow through the tube in the direction indicated by the arrows. The tube 1 is fixed at AA and the tube is excited into an oscillatory angular motion about the x axis, at a resonant frequency determined by the stiffness of the tube, the mass of the tube, and the fluid within
30 the tube. Various means of providing the oscillatory angular motion can be utilised such as a magnetic forcer indicated at 10. The oscillatory angular motion results in Coriolis forces being generated by the fluid as it is constrained to follow this tube motion. These forces will result in an oscillatory twisting of the tube about the z axis by an amount proportional to the mass flow rate and inversely proportional to
35 the tube stiffness. The degree of twist and consequently the mass flow rate is

obtained by computing the difference in the transit times of the points 11 and 12 through a reference x,z plane.

This basic design of Coriolis mass flow meter is still relatively unchanged although a variety of different tube parameters, including bent tubes, straight tubes, single tubes and split tubes, have been tried to improve performance and overcome the sensitivity of earlier designs to various field and environmental effects such as temperature, pressure, vibration and mechanical stress.

10 The principal problem with this basic design is that it is barely viable. It relies on the elastic properties of the flow tube and hence the design is always a compromise between maximising the tube diameter for low pressure drop and minimising the tube stiffness for high flow sensitivity. A larger diameter tube is stiffer and twists less. Consequently, the wall of the flow tube must be thin to minimise flexural
15 stiffness which in combination with high flow velocities can lead to stress and tube erosion problems.

As a result, both the pressure drop across current Coriolis flow meters and the drop in velocity of the fluid flow is large compared with other types of flow meter.

20 Another problem is that the signals to be measured are extremely small and so can lead to inaccuracies. Typical twists in the tube are less than $10\mu\text{m}$ and transit time differences between the points 11 and 12 are of order $10\ \mu\text{s}$. Current Coriolis flow meters are therefore sensitive to external influences as mentioned above, and suffer from zero instability which limits their available range. They also depend on the
25 stability of the elastic properties of the flow tube which limits their potential fractional accuracy.

One reason for the design remaining relatively unchanged is that the density of the flowing fluid can be obtained from the resonant frequency of the tube or tubes.
30 However, this density measurement is also dependent on the elastic properties of the flow tube(s) and is non-linearly related to the measure resonant frequency.

Figure 3 shows a Coriolis flow meter of the invention which is similar to the flow meter shown in Figure 2 except that the flow meter can be driven in an accurately
35 controlled oscillatory motion about the axis AA (see Figure 2) at a frequency that is

not necessarily a mechanical resonance of the flow tubing. The flexible couplings 21 and 22 facilitate this motion. The frequency and the amplitude of this torsional oscillation are chosen to enhance the performance of the meter and both these parameters are actively controlled during flow measurements.

5

The flow rate is obtained by measuring the oscillatory bi-directional force in the Y direction at point 23, this force being proportional to the precessional torque induced about the X axis 24, 25 due to the Coriolis effect. The force may be measured by a sensitive and accurate sensor such as an electromagnetic force
10 balance device which also prevents the flow tube from rotating about the axis 24, 25.

The flexible couplings 26, 27 are utilised to ensure there are no significant forces at the point 23 resulting from tube stiffness.

15

Phase sensitive measurement of the force at 23 can be utilised to improve the signal to noise ratio and hence the precision of the flow measurement. The tube diameter can be relatively large to keep both the fluid flow velocity and the pressure drop across the flow meter small without degrading the performance of the meter. The
20 fluid density can be derived from the oscillatory torque required to rotate the flow tube and the fluid within the tube about the axis AA which will be directly proportion to fluid density. This torsional drive could be electromagnetic in which case the fluid density will be proportional to the drive current.

25 In an alternate form of the invention, if the plane of the flow meter is horizontal instead of vertical as indicated in Figure 3, the fluid density can be obtained from the gravitational torque of the fluid in the tube acting about the axis 24, 25. In this form the fluid density will be proportional to the average force at 23 in the y direction. The use of relatively large tube diameter will improve the accuracy of the
30 density measurement by increasing either the mass of fluid accelerated into torsional oscillation or the mass of fluid exerting a force at the point 23 due to gravity.

The essential feature of the invention is the provision of the flexible couplings which
35 enables the sensing and oscillatory drive components to be changed. For example a

variation of the modification shown in Figure 3 may have the same basic configuration as the mass flow meter shown in Figure 2 and in this variation the oscillatory motion is applied at the point 23 about the axis 24, 25 and by utilising bi-directional force sensors to measure the fluid mass flow at points 24 and 25.

5

Variations of the invention can be applied by utilising a double loop version of the mass flow meter indicated in Figure 3 to which two tubes are located adjacent to each other and with the fluid flow through the tubes being in the same direction while the oscillatory motions of the two tubes are separated in phase by 180°. In 10 this case the sensor at 23 will measure the difference in force between the two loops.

In a yet further variation of the double loop version the two tubes can be oscillated in unison about the axis AA and the flows can be in the tubes in opposite directions.

15

The foregoing describes the invention and modifications as will be obvious to those skilled in the art are intended to be included within the scope of the invention, as defined in the following claims.

CLAIMS:

1. A fluid flow meter comprising a tube curved about a first axis and mounted via flexible couplings for oscillatory motion about a second axis, means to drive the tube in a controlled oscillatory motion about said first axis to generate in fluid flowing in the tube a measurable bi-directional force, and means arranged to measure the bi-directional force in the direction of said first axis and to derive the fluid flow therefrom.
2. A fluid flow meter according to claim 1 wherein said first axis is a vertical axis.
3. A fluid flow meter according to claim 1 wherein said first axis is a horizontal axis and fluid density is obtained from the gravitational torque of the fluid in the tube acting about a horizontal axis.
4. A fluid flow meter according to claim 1 comprising two curved tubes, each mounted via flexible couplings for oscillatory motion and means to drive the tubes in a controlled oscillatory motion in which the motion of one tube is 180° out of phase with the motion of the other tube and means to measure the difference in oscillatory force between the two tubes and derive the fluid flow therefrom.
5. A fluid flow meter according to any one of claims 1 to 4 wherein said curved tube or tubes is or are a U-shaped tube or tubes.
6. A fluid flow meter according to claim 1 wherein the tube is in the form of a loop.
7. A fluid flow meter according to any one of claims 1 to 5 in which the or each tube is mounted by a second pair of flexible couplings arranged to minimise forces on the tube due to inherent stiffness of the tube.

Figure 1

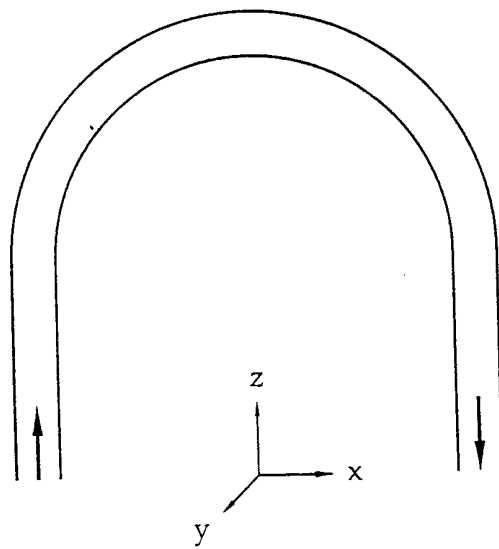


Figure 2

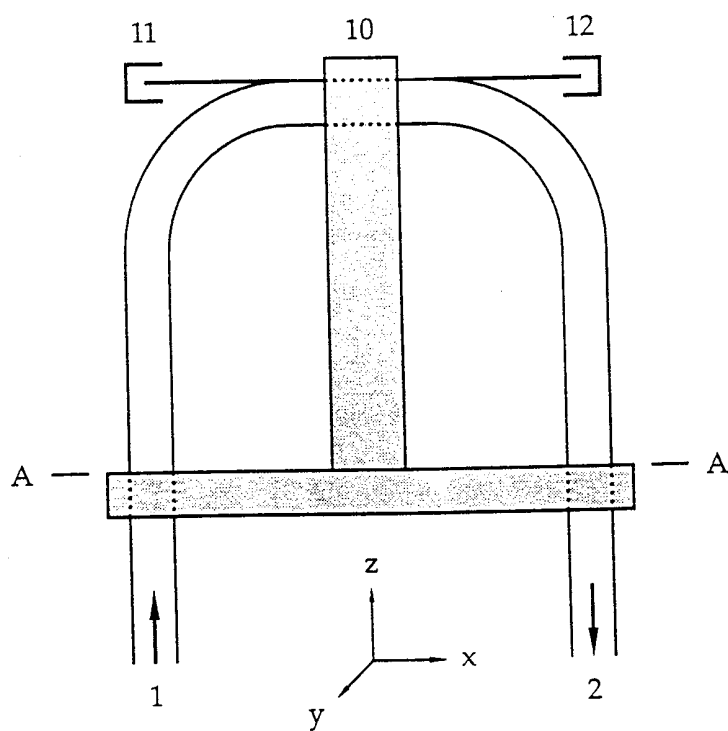
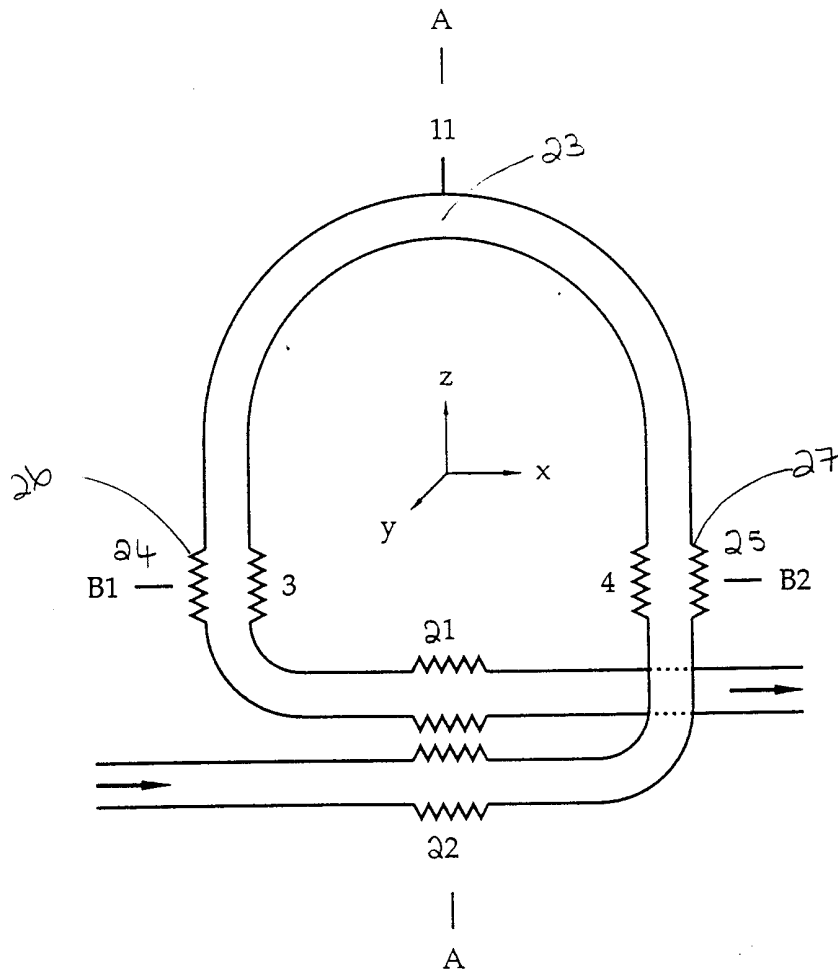


Figure 3



INTERNATIONAL SEARCH REPORT

International application No.
PCT/NZ 99/00103

A. CLASSIFICATION OF SUBJECT MATTER		
Int Cl ⁶ : G01F 1/84		
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) IPC GO1F 1/76, 1/78, 1/80, 1/84		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched AU IPC: AS ABOVE		
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C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	Patent Abstracts of Japan, P 721, page 44 JP 63-18219 A (OVAL ENG CO LTD) 26 January 1988 See abstract	1-7
Y	Patent Abstracts of Japan, P 1394, page 142 JP 4-109121 A (YOKOGAWA ELECTRIC CORP) 10 April 1992 See abstract	1-7
Y	Patent Abstracts of Japan, P 250, page 140 JP 58-178217 A (YOKOGAWA DENKI SEISAKUSHO KK) 19 October 1983 See abstract	1-7
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Y	US 4895031 A (CAGE D) 23 January 1990 See whole document	1-7
Y	US 4729243 A (FRIEDLAND B <i>et al</i>) 8 March 1988 See whole document	1-7
Y	US 4803867 A (DAHLIN E) 14 February 1989 See whole document	1-7
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Y	US 4187721 A (SMITH J) 12 February 1980 See whole document	1-7
Y	US 4856346 A (KANE M) 15 August 1989 See whole document	1-7

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
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Patent Document Cited in Search Report		Patent Family Member					
US	4895031	CA	1282614	DE	3650427	EP	235274
		EP	553939	JP	63501034	WO	8701444
		US	4955239				
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