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(54) Fluid-flow monitoring apparatus

(57) Apparatus for monitoring the flow of a fluid in a tube (1) comprises first and second temperature-sensitive resistors 8,9 attached to the outer surface of the tube wall. The first resistor 8 is heated by a heater 7 mounted alongside the resistor. The first and second resistors are connected in a bridge circuit 20 with third and fourth resistors 17,18 which are not affected by the flow. Inputs of a differential amplifier 22 are connected to opposite corners 23,24 of the bridge, and the amplifier output is connected to the heater. The amplifier supplies whatever level of heating current is required to maintain a constant state of balance of the bridge, i.e. a constant temperature difference between the first and second resistors. The greater the fluid flow, the larger will be the heater current required to maintain the temperature difference, and that current therefore provides a measure of the fluid flow. A feedback circuit 27,28,29 is provided between the output and the inverting input of the amplifier. This circuit ensures a stable response, the optimum speed of response, to changes in flow rate. The apparatus may be used in a heat flow measuring system.

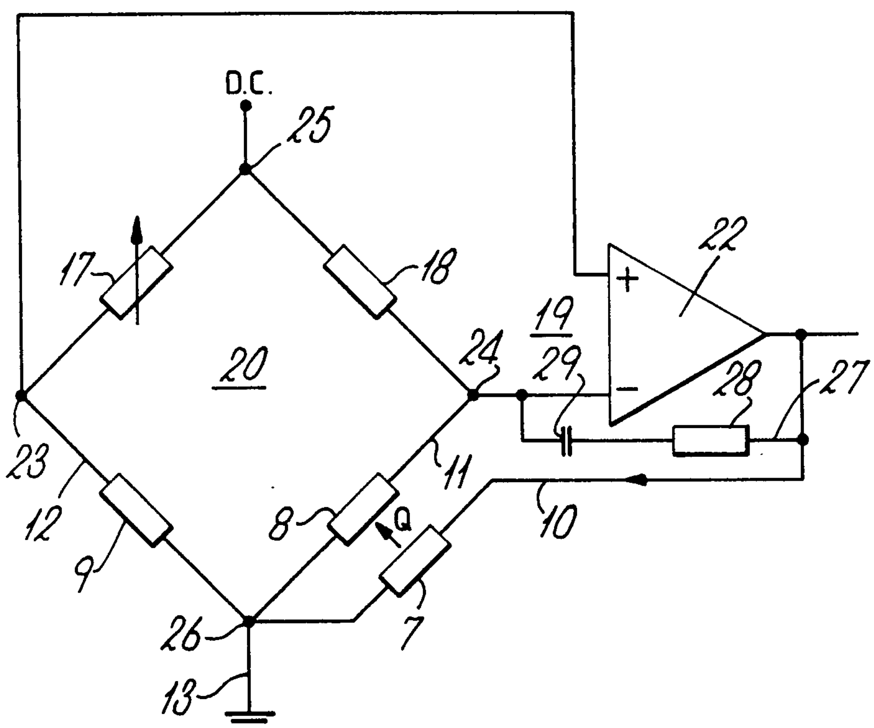

Fig. 3.

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The drawing(s) originally filed was/were informal and the print here reproduced is taken from a later filed formal copy.

Fig.1.

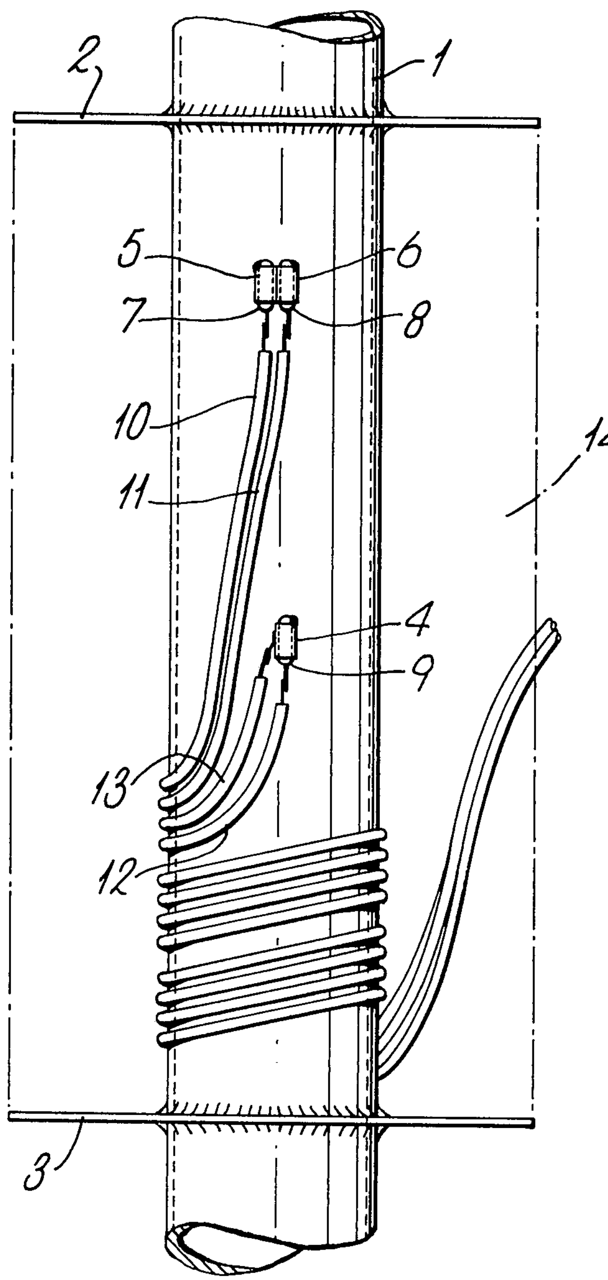


Fig. 2.

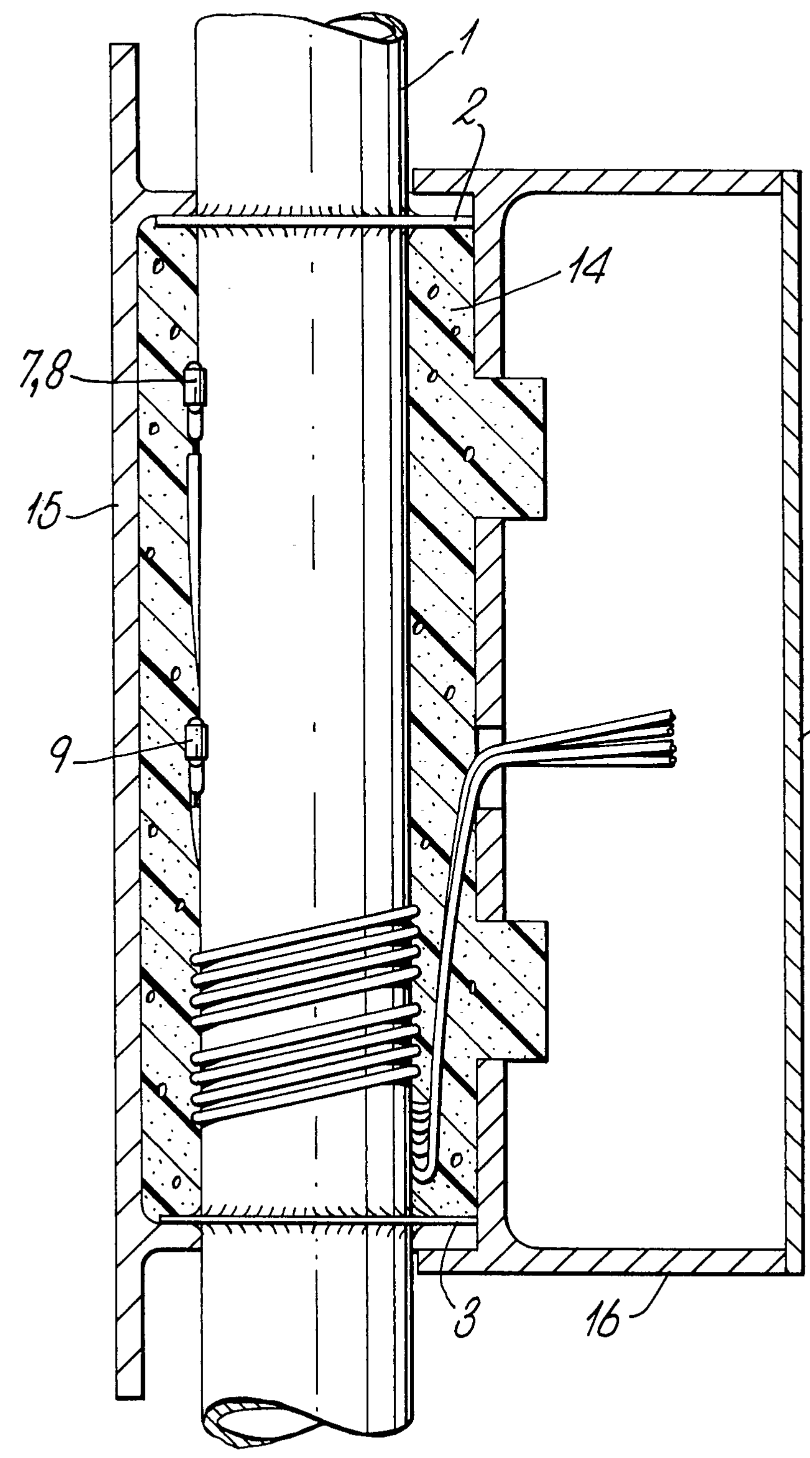
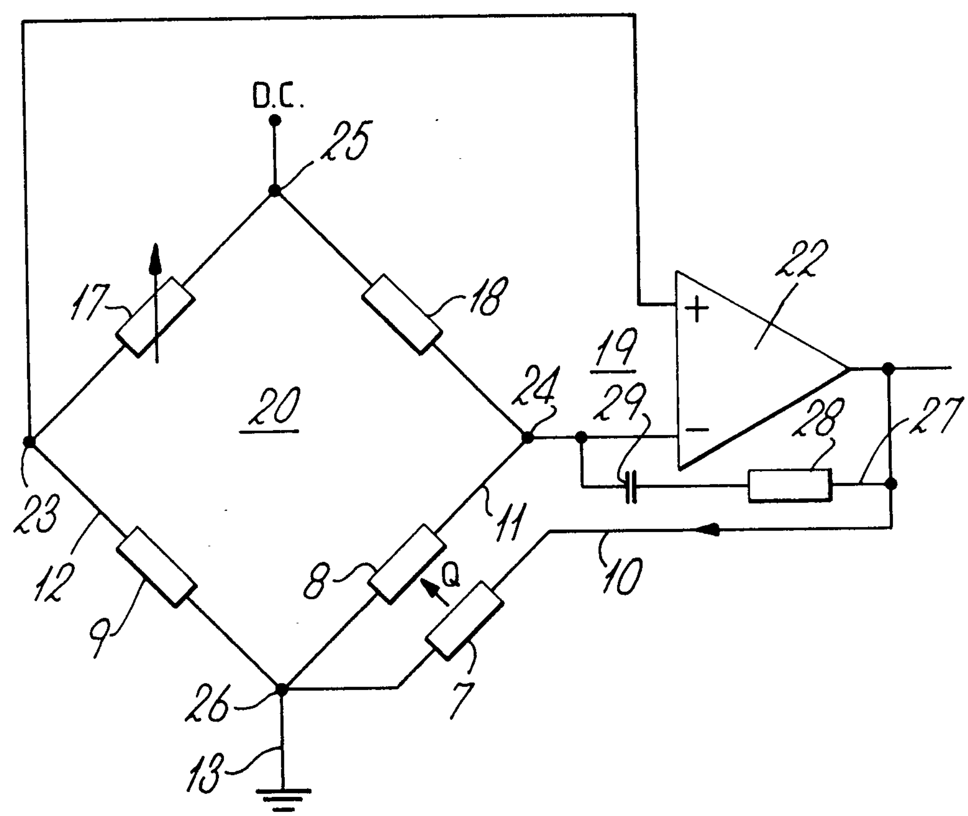


Fig. 3.



SPECIFICATION

Fluid-flow monitoring apparatus

This invention relates to apparatus for monitoring the flow of a fluid, for example the flow of coolant in a cooling system.

Where a flowing coolant, such as water, is used to cool equipment, it is often essential that the coolant flow through one or more paths shall be continuously monitored, in order to check that the flow rate is adequate. If the flow rate is not adequate, the monitoring apparatus can inhibit starting of the equipment and/or cause operation of an alarm and/or cause the equipment, if already running, to shut down.

A number of types of flow monitoring apparatus have been used previously, operating on different principles. For example, the pressure drop across an orifice, the lifting of a float within a tube, and the tipping of a small bucket which is filled by the coolant flow and which tips when the rate of inflow of coolant exceeds the rate of outflow through a hole in the bottom of the bucket have all been used as an indication of flow rate. However, the types of apparatus operating on these principles have suffered from malfunction due to blockage of orifices or sticking of moving parts which are in contact with the coolant.

A further type of known apparatus comprises two temperature-sensitive resistors which are located within the coolant flow. One of the resistors is heated by an adjacent heating element. The temperature-sensitive resistors are connected as two arms of a Wheatstone bridge, with reference resistors in the other two arms. Since the temperature-sensitive resistors are both in the coolant flow, variations in the coolant temperature will be cancelled out, and the bridge will, in effect, monitor the temperature of the heated resistor. The temperature attained by that resistor as a result of the action of the heating element will vary in dependence upon the rate of flow of the coolant over the heated resistor, which is tending to cool the resistor. The output of the bridge therefore gives an indication of the coolant flow rate.

However, as mentioned above, the sensing resistors have been located in the coolant flow and, in order to resist erosion by the coolant have been formed of platinum wire or have comprised thermistors mounted in thin-walled tubes. In either case, the sensor resistors have protruded into the flow and have therefore been vulnerable to erosion and corrosion and have given rise to turbulence in the flow.

In another known type of flowmeter, two heated resistance thermometers have been located either within the flow or on the outside of a tube carrying the flow. When air or other fluid flows through the tube, the upstream thermometer will give up some of its heat to the fluid. As the fluid is thereby warmer when it reaches the second (downstream) thermometer, that thermometer will be cooled less than the first thermometer. There is, therefore, an imbalance between the two thermometers, and the degree of this imbalance provides a measure of the fluid flow rate. Such an apparatus is, however, likely to be inaccurate and slow to respond because of the extremely small temperature difference which is being monitored. Each thermometer heater gives out quite a small amount of heat, so the amount of heat gained by the fluid flowing past the first thermometer is very small. The cooling effect at the second thermometer will therefore be only very slightly different from that the first thermometer, so the imbalance will be very small.

It is an object of the present invention to provide an improved fluid-flow monitoring apparatus.

According to the invention, fluid-flow monitoring apparatus comprises a tubular member for carrying the fluid flow; first and second temperature-sensitive resistance means spaced from each other and positioned for good heat-conduction relationship with the fluid but out of contact with the fluid; a heating element for heating the first resistance means; and means to supply heating current to the heating element and to control the magnitude of the heating current to maintain a substantially constant temperature difference between the first and second resistance means despite cooling of the first resistance means by the fluid flow, whereby the magnitude of the heating current provides an indication of the flow rate.

One embodiment of the invention will now be described, by way of example, with reference to the accompanying drawings, in which

Figure 1 is a schematic view of a flow tube of a monitoring apparatus in acccrdance with the invention, encapsulated in a block of thermally-insulating material,

Figure 2 is a side view of the flow tube assembled in a housing, with an enclosure for an electronic control circuit attached thereto, and

Figure 3 is a block schematic diagram of the control circuit.

Referring to Figures 1 and 2 of the drawings, a stainless steel tube 1 of, for example, 0.5 to 0.75 mm wall thickness and 300 mm length has stainless steel location plates 2 and 3 soldered thereto at locations approximately 1/4 of the tube length in from respective ends of the tube. The diameter of the tube 1 is selected to be similar to that of pipes used elsewhere in the cooling system. The bore of the tube is smooth, and has no restrictions to impede the flow of the coolant therethrough, and no elements protruding into the flow path to become corroded by contact with the coolant.

Short lengths 4, 5 and 6 of thin-walled copper tube are soldered to the outside surface of the tube 1, the tubes 5 and 6 being located in good thermal contact with each other, and the tube 4 being spaced therefrom and aligned therewith along the direction of coolant flow. The spacing between the tubes 4 and 5 is, say, 50 mm.

A heating element 7 is a close fit within the tube 5, and matched temperature-sensitive resistors 8 and 9 are close fits within the tubes 6 and 4, respectively. One end of the element 7 and one end of the resistor 8 are soldered to the outside of the tube assembly 5, 6 and one end of the resistor 9 is similarly soldered to the surface of the tube 4. The other ends of the heating element and the resistors are soldered to connecting wires 10-12, and a wire 13 provides a common ground connection for the sensors and the heater. The wires 10-13 are secured to the surface of the tube 1, for example by adhesive tape, and are wrapped around the pipe a number of turns to reduce heat conduction away from the sensors along the wires and to ensure that no strain is applied to the soldered connections.

The tube is mounted in a housing 15, with the plates 2 and 3 in contact with the inner surface of respective ends of the housing, and with the ends of the tube 1 projecting from the housing. The section of the tube 1 between the location plates 2 and 3 is encapsulated in a block 14 of polyurethane foam, using the housing 15 as a mould. This encapsulation ensures that the operation of the temperature-sensitive resistors 8 and 9 is substantially unaffected by the ambient temperature of the environment in which the apparatus is operating, and that the small amount of heat generated by the element 7 is confined to the region of the resistor 8.

The open side of the housing 15 is covered by an enclosure 16, in which reference resistors 17 and 18 and other components of an electronic sensing circuit 19 (Figure 3) are mounted. The temperature-sensitive resistors 8 and 9 and the resistors 17 and 18, which are not temperature-sensitive, together form a resistance bridge 20. The enclosure is covered by a lid 21.

Although the temperature-sensitive resistors 8 and 9 are mounted on the outside of the tube 1, i.e. away from the direct action of the fluid flow, it has been found that the use of a thin-walled stainless steel tube for carrying the coolant allows good transfer of heat from the resistors 8 and 9 to the coolant. It is, of course, essential that the resistors 8 and 9 be mounted sufficiently far apart so that the heater 7 does not affect the resistor 9 by conduction of heat along the tube 1. The alignment of the resistors 8 and 9 along the length of the tube 1 is not essential; the resistor 9 could be mounted diametrically opposite to the resistor 8, provided that the spacing between those resistors is adequate.

The mounting of the sensor resistors on the outside of the tube 1 would, however, cause the apparatus to be slow to respond to changes in the fluid flow rate. The present invention therefore includes means for speeding up the reaction of the sensors. Referring to Figure 3, the latter means comprises a differential amplifier 22, the two inputs of which are connected to opposite corners 23 and 24 of the bridge 20. The other corners 25 and 26 are connected to a stabilised d.c. supply and to the ground line 13, respectively. The output of the amplifier 22 supplies heating current to the heater element 7 via line 10, and feeds a feedback signal to the inverting input of the amplifier 22 via a line 17, a feedback resistor 28 and a capacitor 29. The values of the resistor 28 and the capacitor 29 are chosen to stabilise the system and to optimise its speed of response when it reacts to flow rate changes and to the switching-on of the power supply.

In operation of the apparatus, the pipe 1 is connected into the equipment cooling system to conduct the coolant flow which is to be monitored. The heater element 7 is energised via the line 10, and the resistor 8 is heated thereby. The resistor attains the same temperature as the fluid, by virtue of being attached to the wall of the tube 1, and hence attains a resistance value which is dependent on the coolant temperature. Since the resistor 8 is attached to the tube 1 and is also in proximity to the heater 7, it attains a temperature some degrees above the coolant temperature. The precise temperature difference between the resistor 8 and the resistor 9 can be adjusted using the resistor 17. The feedback circuit comprising the amplifier 22 and the heater 7 brings the system into a state of balance by supplying to the heater that current required to maintain this precise temperature difference. The energy dissipated in the region around the heater 7 and the resistor 8, while this temperature difference is being maintained, will depend on the flow rate. When the system is in a state of balance, the current through the line 27 is zero and, because the amplifier 22 has a high open-loop gain, the temperature difference between the resistors 8 and 9 is substantially independent of the flow rate.

It would be possible to omit the capacitor 29 from the amplifier feedback loop. However, this is not the preferred arrangement, because the value of the resistor 28 would then have to be selected to obtain stability, resulting in a non-optimal dynamic response, a reduced output voltage range and a temperature difference between the resistors 8 and 9 which is dependent on the flow rate.

As a result of the operation of the feedback circuit, the output of the amplifier 22 is a function of the fluid flow rate, and this output can be used to give a flow rate indication, or to activate control gear (not shown) to switch off the cooled equipment if the fluid flow is not adequate.

At a given flow rate the amplifier output voltage will depend on the temperature difference between the resistors 8 and 9. During calibration this can be adjusted, using the resistor 17, so that the temperature difference is high enough to make the effect of drift in the bridge resistors and the amplifier on the flow rate signal negligible, but not so high that the power consumption is excessive. Given the power consumption at the maximum flow rate, the resistance of the heater 7 is chosen to provide a reasonable voltage range for control equipment and together with the maximum voltage available from the amplifier should provide for sufficient dynamic forcing when the switch reacts to a flow change from low to high flow rate.

In the preferred design the amplifier 22 will supply a finite minimum power at the minimum flow rate. This minimum power could alternatively be supplied from a fixed and separate source. The amplifier and feedback circuit would then supplement this source at flow rates above the minimum. This is not used in the preferred embodiment, however, because a stabilised power supply and extra connections to the heater, or a second heater, would be necessary.

Due to the feedback action and the amplification of the amplifier 22, the circuit responds rapidly to changes in fluid flow rate.

Due to the inherent non-linearity of temperature-sensitive resistors, changes in the temperature of the coolant may not be exactly cancelled out by the location of both of the resistors 8 and 9 in contact with the wall of the tube 1. However, by inserting an appropriate resistor, not shown, in series with the resistor 9, determined as a function of the setting of the resistor 17, the effect of the non-linearity can be reduced. The position of the resistors 8 and 9 and the heater 7 on the outside of the tube 1, and therefore downstream of a length of undisturbed flow, ensures that after calibration the output is independent of temperature over a reasonable flow rate and temperature range.

In the above-described embodiment the resistors 8 and 9 and the heater 7 are mounted on the outer surface of the tube 1 through which the fluid flows. However, in an alternative embodiment (not shown) those components could be mounted on the inner surface of an auxiliary thin-walled tube, which is then mounted within a flow tube of larger diameter than the auxiliary tube, the fluid flow then being carried in the annular space between the inner surface of the flow tube and the outer surface of the auxiliary tube. The auxiliary tube is preferably formed of stainless steel.

The inventive principle of the present invention, i.e. control of the heating current to re-establish balance in the system and monitoring the heating current level to determine the flow rate, can be used in respect of switching or flow metering applications, as mentioned above. The apparatus can be used in relation to any suitable fluids including gases, which fluids need not be in use as coolants. Hence, any suitable fluid flow may be monitored.

The principle may also be used in fluid level indicators and in heat flow meters for fluids. If a liquid covers the sensors, the apparatus will respond to the change in cooling effect and therefore can be used for level detection. For heat flow applications where one is interested, say, in the heat flow into an equipment or a building, the apparatus gives a signal proportional to flow and the passive sensor 9 gives a signal proportional to the temperature of the liquid passing over it. All that is necessary then is to place another passive sensor on a downstream pipe (for example a pipe containing the fluid leaving the equipment or building, if the flow meter is connected in the ingoing pipe), subtract the two sensor readings and multiply by the flow. The resultant signal is proportional to the heat taken by the equipment.

CLAIMS

1. Fluid-flow monitoring apparatus, comprising a tubular member for carrying the fluid flow; first and second temperature-sensitive resistance means spaced from each other and positioned for good heat-conduction relationship with the fluid but out of contact with the fluid; a heating element for heating the first resistance means; and means to supply heating current to the heating element and to control the magnitude of the heating current to maintain a substantially constant temperature difference between the first and second resistance means despite cooling of the first resistance means by the fluid flow, whereby the magnitude of the heating current provides an indication of the flow rate.

2. Apparatus as claimed in claim 1, further comprising third and fourth resistance means located to be substantially unaffected by the fluid flow and connected with the first and second resistance means to form a resistance bridge circuit, the means to supply heating current being operative to control the magnitude of the heating current in response to the state of balance of the bridge.

3. Apparatus as claimed in claim 2, wherein the means to supply heating current comprises a differential amplifier having inverting and non-inverting inputs coupled to respective opposite corners of the bridge.

4. Apparatus as claimed in claim 3, wherein a feedback circuit is connected between the output of the amplifier and its inverting input, the feedback circuit comprising fifth resistance means.

5. Apparatus as claimed in claim 4, wherein

the feedback circuit further comprises capacitance means connected in series with the fifth resistance means.

6. Apparatus as claimed in any preceding claim, wherein the first and second resistance means are attached to the outer surface of the tubular member.

7. Apparatus as claimed in any preceding claim, wherein the tubular member is formed of stainless steel.

8. Apparatus as claimed in claim 7, wherein the tubular member has a wall thickness of 0.5 to 0.75 mm.

9. Apparatus as claimed in any one of claims 1 to 5, wherein the first and second resistance means are attached to the inner surface of a closed auxiliary tube which is mounted within the tubular member, there being a space between the inner surface of the tubular member and the outer surface of the auxiliary tube to receive the fluid flow.

10. Apparatus as claimed in claim 9, wherein the auxiliary tube is formed of stainless steel.

11. Fluid-flow monitoring apparatus substantially as hereinbefore described with reference to the accompanying drawings.

12. Heat-flow monitoring apparatus, comprising fluid-flow monitoring apparatus as claimed in any preceding claim, together with first fluid temperature-sensing means responsive to the resistance of the second resistance means for sensing the temperature of the fluid.

13. Apparatus as claimed in claim 12, wherein the first fluid temperature sensing means is positioned at an upstream point of the fluid flow, the apparatus further comprising second temperature sensing means at a downstream point of the flow; means to determine the difference in fluid temperature between the two points; and to compute therefrom, and from the rate of flow, heat lost or gained by the fluid between those points.

14. Apparatus for monitoring liquid level in a container, comprising first and second temperature-sensitive resistance means to be located at respectively different levels in the container; a heating element for heating the first resistance means; means to supply heating current to the heating element; and means response to change in temperature at one or both of the resistance means to indicate the presence or absence of liquid at the respective level.

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