United States Patent [19]

Kelsey et al.

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[45] **Date of Patent: Mar. 29, 1988**

[54] **MASS FLOW METER**

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[21] Appl. No.: **809,658**

[22] Filed: **Dec. 16, 1985**

[51] **Int. Cl.**[4] **G01F 1/84**

[52] **U.S. Cl.** **73/861.38**

[58] **Field of Search** 73/861.37, 861.38

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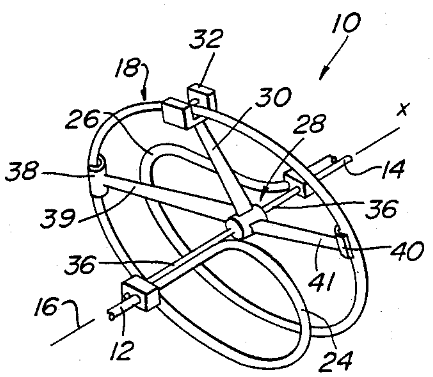
Primary Examiner—Herbert Goldstein
Attorney, Agent, or Firm—Seidel, Gonda, Goldhasmmer & Abbott

[57] **ABSTRACT**

A mass flow meter for placement in line within a preexisting process line. The flow meter having a conduit forming a substantially free floating spiral or circular loop which is symmetrical about the axis line defined by the process line. A driving transducer extending radially from a bracket on a support beam which is positioned along the axis line and attached to the inlet and outlet end of the conduit. The driver imparting an alternating deflection to the loop which is substantially perpendicular to the fluid flow within the loop and parallel to the axis line. Sensing transducers are positioned along the periphery of the loop, displaced equidistant from the driving transducer along its circumference for determining the deflection signature of the loop. The deflection of the loop in response to the fluid reaction forces is measured without reference to a specific fixed axis or position of the loop. This acceleration signature is correlated to the mass flow rate of the fluid through the conduit.

14 Claims, 8 Drawing Figures



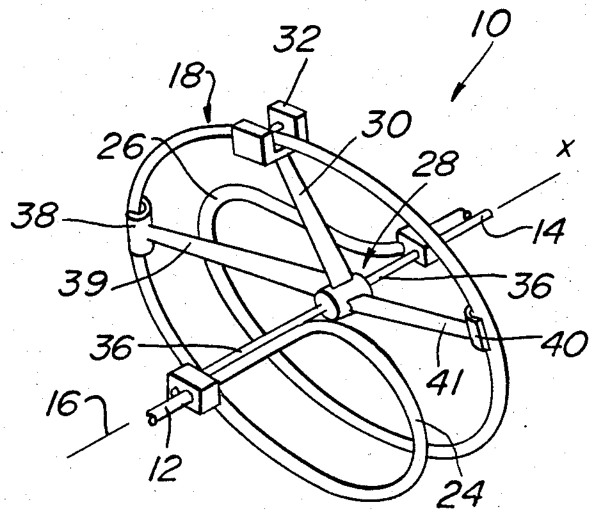

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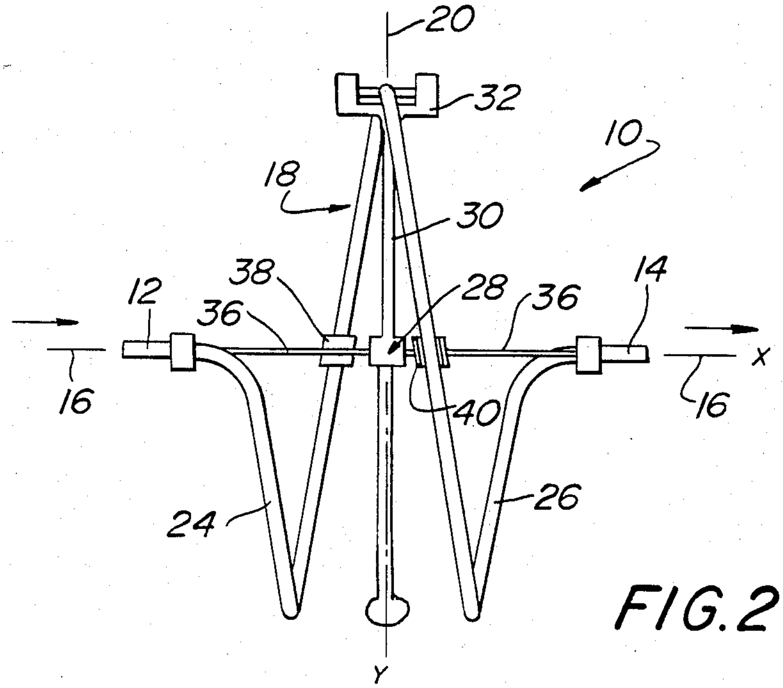
FIG. 1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Y

FIG. 2

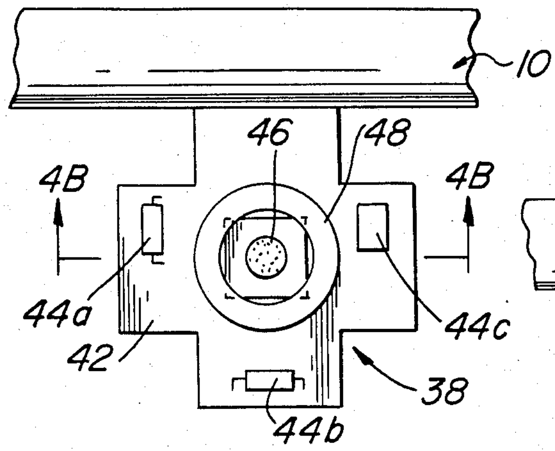


FIG. 4A

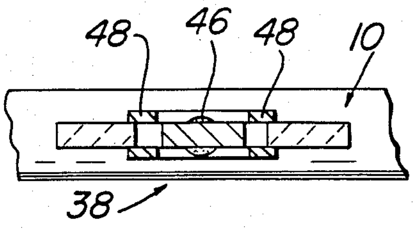


FIG. 4B

FIG.3

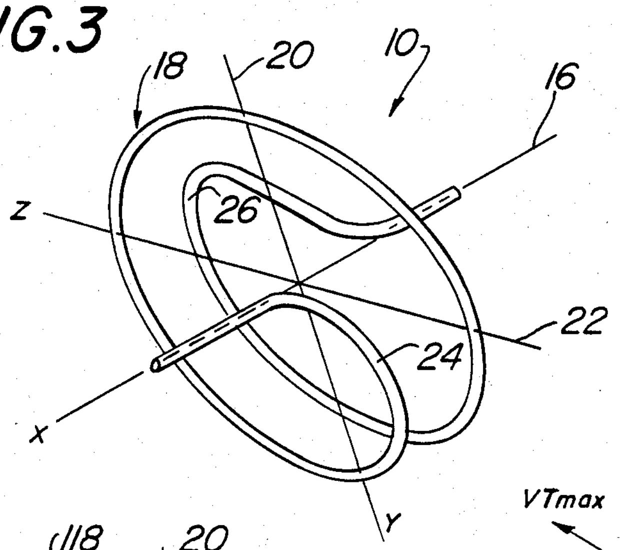
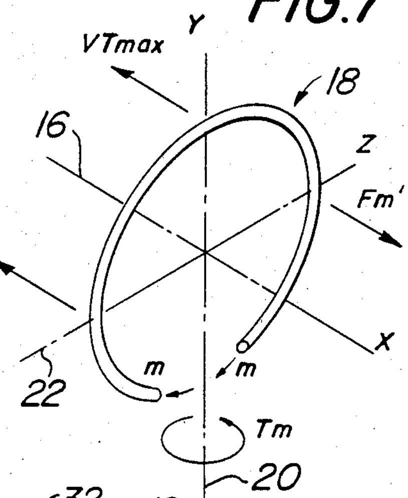


FIG.7



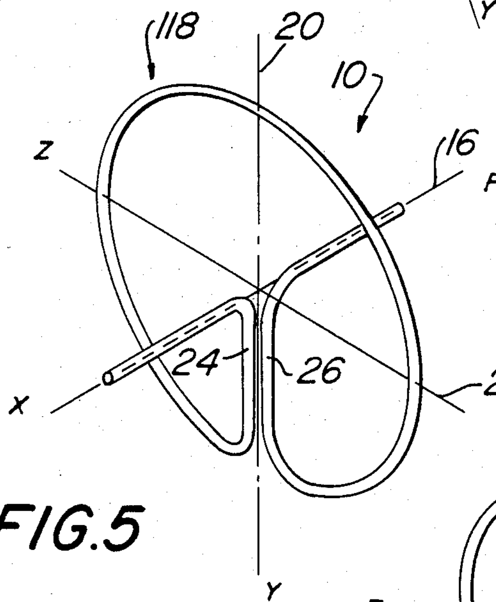


FIG.5

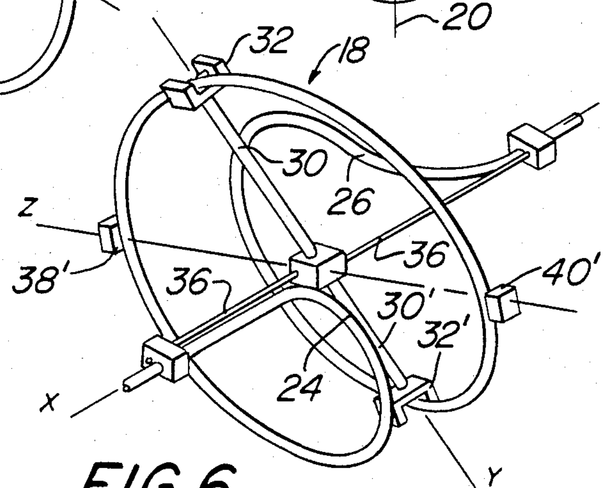


FIG.6

MASS FLOW METER

BRIEF SUMMARY OF THE INVENTION

This invention relates to a mass flow meter which measures Coriolis or gyroscopic type reaction forces to determine the mass flow of a fluid or slurry within a conduit. Paricularly this invention incorporates a conduit loop having an inlet end and an outlet end positioned substantially along a single axis which is typically defined by a line of existing piping. The loop is alternately deflected in a direction orthogonal to the flow within the conduit. The alternating deflections or oscillations of the conduit imparts a transverse angular momentum to the fluid flowing through the loop. The fluid reacts with a repetitive and measurable force against the wall of the conduit causing a transverse deflection of the loop. The reaction of the fluid on the conduit is proportional to the magnitude and direction of the fluid mass flow.

BACKGROUND OF THE INVENTION

The invention relates to a mass flow metering device which operates within a defined fluid stream. Such metering devices are desirably constructed without internal moving parts which may be contaminated by the fluid within the stream. The principle of the invention is based on the known fact that a fluid flowing through a conduit or tube which experiences an acceleration orthoginal to the direction of its flow, will interact with the conduit wall with a reaction force which is directly proportional to the mass flow of the fluid within the conduit. The reaction force generated by the fluid against the conduit is generally referred to as a Coriolis force.

Various issued patents describe mass flow meters which utilized the measurement of the fluid reaction forces to determine the mass flow rate. These patents teach various conduit designs and configurations, various means for measuring the reaction forces and various ways of determing the mass flow.

Roth, U.S. Pat. No. 2,865,201, teaches a gyroscopic type flow meter which directly measures the magnitude of the reaction forces on the conduit. Since these forces are created by a continuous oscillation of the conduit, the Roth design is impractical. Similar conduit designs are found in Roth, U.S. Pat. No. 3,276,257, and Henderson, U.S. Pat. No. 3,108,475. The sensitivity of the reaction force measurement in all of these conduit designs is greatly influenced by the oscillatory fluctuations of the meter conduit and by environmental vibrations.

A series of patents, U.S. Pat. Nos. 3,261,205, 3,329,019 and 3,355,944, to Sipin teach the measurement of the fluid reaction forces due to an imparted transverse vibration on a straight conduit, a curved conduit and a U-shaped conduit. The earlier conduit designs in this series attempt to directly measure the reaction forces on the conduit and, therefore, were subject to the same substantial sensitivity deficiencies due to external vibrational influences found in the patents discussed above. In the curved and U-shaped conduit designs, the imparted oscillation creates a torsional bending moment about an, ideally, fixed axis. In the U-shaped design the sensors were required to be referenced to the actual motion of the tube and to a fixed or stationary position. In a working environment each of the Sipin conduit designs are extremely noisy in operation and, basically, ineffective due to inacuracies created by vibrations of the flow meter and the references of the sensors tube unrelated to the fluid reaction force. The drivers, which impart the oscillatory motion to the conduit, are attached to an external casing of the meter. The internal and external vibrational effects causes substantial output deficiencies in the reaction force sensing means and, therefore, greatly effect the calculation of the mass flow rate.

In Smith, U.S. Pat. No. 4,109,524, an attempt was made to separate the oscillation means from the force measurement system. The flow meter disclosed in this patent is cumbersome in application and does not effectively reduce the vibrational effects on the reaction force sensing means.

The first patent to recognize the need for vibrational and noise immunity on the sensing means is Cox et al, U.S. Pat. No. 4,127,028. In Cox each reaction force sensor is referenced to two adjacent cantalevered tubes. The two tubes are oscillated simultaneously in opposite relative directions and, ideally, at the same resonance. The external vibrational influences on the two tubes are intended to be self-cancelling when viewed by the sensors referenced to both tubes. However, the driving means in this design is mounted on a long cantilever arm and includes a large weight at the end of the arm. This structure produces an extremely low vibrational resonance and greatly limits the ability of the cantalevered tube to oscillate about a fixed reference axis. Environmentally induced vibrations, as well as vibrational effects of the driving means continue to influence the Cox measurement sensitivity by affecting the positioning of the tubes differently.

The same deficiencies found in Cox '028 in its reaction force sensing are found in the Smith, U.S. Pat. No. 4,187,721 and its corresponding Reissue No. 31,450. Smith, U.S. Pat. No. 4,422,338, attempts to enhance the sensitivity of the meter by using a frame which surrounds the oscillating tube to act as a fixed sensor reference. In addition, the Smith '338 design utilizes velocity type sensors to create an adjoining reference system such that the zero or reference position of linear type sensors, which record the tube motion due to the fluid reaction forces, is continually adjusted in response to vibrational influences on the meter. However, since the rotational axis of the cantalevered flow meter tube and mounting frame is not stationary, due to the vibrational effects on the meter structure. The effect of adjusting the reference plane of the reaction force sensors, therefore, is minimal. Commonly assigned copending application Ser. No. 809,659 submitted to the Patent Office on Dec 16, 1985 teaches a conduit design which is not cantilevered and is driven preferably directly along the axial line of the pipeline of the defined fluid stream. The structure of this invention overcomes many of the prior art deficiencies in sensing.

It is important to note that in all of the known flow meter designs, as long there is an increasing gradient of transverse velocity from the entrance of the flow meter tube to a point of maximum velocity and a decreasing transverse velocity gradient from the maximum point to the outlet, that there will be a decreasing transverse reaction or Coriolis force gradient in one direction from the inlet to the point of maximum deflection or velocity and a transverse force gradient in the opposite direction from the maximum point to the outlet. The measurement or sensing of these reaction forces created by the

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