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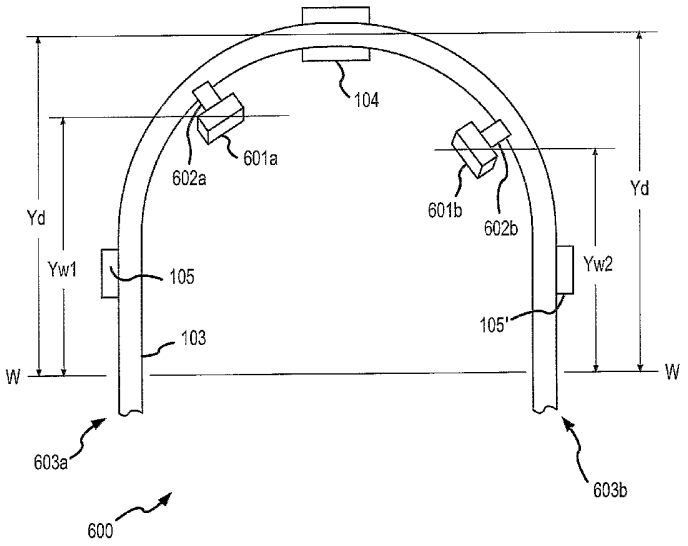
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(54) Title: SPLIT BALANCE WEIGHTS FOR ELIMINATING DENSITY EFFECT ON FLOW



(57) Abstract: A Coriolis flow meter includes at least one flow conduit (103), including a first conduit node (603a) and a second conduit node (603b) and a bending axis W that intersects the flow conduit (103) at the first conduit node (603a) and at the second conduit node (603b). The flow conduit (103) vibrates around the bending axis W. The meter further includes a drive system (104) and a balance system (600) coupled to the flow conduit (103). The balance system (600) includes two or more Y-balance weights (601a, 601b) and two or more attachment members (602a, 602b) that couple the two or more Y-balance weights (601a, 601b) to the flow conduit (103). At least a first Y-balance weight (601a) is coupled to the flow conduit (103) at a first location between the first conduit node (603a) and the drive system (104) and at least a second Y-balance weight (601b) is coupled to the flow conduit (103) at a second location between the drive system (104) and the second conduit node (603b).

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SPLIT BALANCE WEIGHTS FOR ELIMINATING DENSITY EFFECT ON FLOW

Background of the Invention

1. Field of the Invention

The present invention relates to force balancing a Coriolis flow meter using two or more split Y-balance weights.

2. Statement of the Problem

Vibrating conduit sensors, such as Coriolis mass flow meters, typically operate by detecting motion of a vibrating conduit that contains a material. Properties associated with the material in the conduit, such as mass flow, density and the like, in the conduit may be determined by processing signals from motion transducers associated with the conduit, as the vibration modes of the vibrating material-filled system generally are affected by the combined mass, stiffness and damping characteristics of the containing conduit and the material contained therein.

A typical Coriolis mass flow meter includes one or more conduits that are connected inline in a pipeline or other transport system and convey material, *e.g.*, fluids, slurries and the like, in the system. Each conduit may be viewed as having a set of natural vibration modes including, for example, simple bending, torsional, radial, and coupled modes. In a typical Coriolis mass flow measurement application, a conduit is excited in one or more vibration modes as a material flows through the conduit, and motion of the conduit is measured at points spaced along the conduit. Excitation is typically provided by an actuator, *e.g.*, an electromechanical device, such as a voice coil-type driver, that perturbs the conduit in a periodic fashion. Mass flow rate may be determined by measuring time delay or phase differences between motions at the transducer locations.

The magnitude of the time delay is very small; often measured in nanoseconds. Therefore, it is necessary to have the transducer output be very accurate. Transducer accuracy may be compromised by nonlinearities and asymmetries in the meter structure or from motion arising from extraneous forces. For example, a Coriolis mass flow meter having unbalanced components can

vibrate its case, flanges and the pipeline at the drive frequency of the meter. This vibration perturbs the time delay signal in an amount that depends on the rigidity of the mount. Additionally, a Coriolis flow meter determines the density of the flow material based on the frequency of the drive mode. If the drive mode includes motion of the case, flanges, and pipeline, the performance of the density measurement can be adversely affected. Since the rigidity of the mount is generally unknown and can change over time and temperature, the effects of the unbalanced components cannot be compensated and may significantly affect meter performance. The effects of these unbalanced vibrations and mounting variations are reduced by using flow meter designs that are balanced and by using signal processing techniques to compensate for unwanted components of motion.

The balanced vibration discussed above involves only a single direction of vibration: the Z-direction. The Z-direction is the direction that the conduits are displaced as they vibrate. Other directions, including the X-direction along the pipeline and the Y-direction perpendicular to the Z and X-directions, are not balanced. This reference coordinate system is important because Coriolis flow meters produce a secondary sinusoidal force in the Y-direction. This force creates a meter vibration in the Y-direction that is not balanced, resulting in meter error.

One source of this secondary force is the location of the mass of the meter driver assembly. A typical driver assembly consists of a magnet fastened to one conduit and a coil of conductive wire fastened to another conduit. The Y-vibration is caused by the center of mass of the driver magnet and the center of mass of the driver coil not lying on the respective X-Y planes of the centerline(s) of the flow conduit(s). The X-Y planes are necessarily spaced apart to keep the conduits from interfering with one another. The centers of mass of the magnet and/or coil are offset from their planes because the coil needs to be concentric with the end of magnet to be at the optimum position in the magnetic field.

A flow conduit, when driven to vibrate, does not truly translate but rather cyclically bends about the locations at which it is fixed. This bending can be approximated by rotation about the fixed point(s). The vibration is then seen to be a cyclic rotation through a small angle about its center of rotation, CR. The angular vibration amplitude is determined from the desired vibration amplitude in the Z direction and the distance, d, from the center of rotation of the conduit center at the

driver location. The angular amplitude of vibration, $\Delta\theta$, is determined from the following relation:

$$\Delta\theta = \arctan(\Delta Z/d) \quad (1)$$

The offset of the driver component (magnet or coil assembly) center of mass from the conduit centerline causes the driver component center of mass to have a Y-component of its vibration. The driver component mass usually has an offset in the Z-direction that is at least equal to the conduit radius. The angular offset, Φ, from the conduit centerline is thus not negligible. The driver component mass oscillates about its offset position with the same angular amplitude as the flow conduit, $\Delta\theta$. Approximating the motion of the driver mass as being perpendicular to the line connecting the driver center of mass with the center of rotation, CR, the driver mass Y-direction motion, ΔY_m, can be solved from the following:

$$\Delta Y_m = \Delta Z \sin(\Phi) \quad (2)$$

The Y-direction motion of the driver component mass causes the whole meter to vibrate in the Y-direction. Conservation of momentum requires that, for a freely suspended meter, the Y-direction vibration of the entire meter is equal to the Y-direction vibration amplitude of the driver mass times the ratio of the driver mass divided by the meter mass. This Y-vibration of the entire meter is a direct result of the desired conduit vibration in Z in conjunction with the angular offset of the drive components' centers of mass. This coupling between the desired conduit vibration and the undesired Y-vibration of the entire meter means that damping of the meter Y-vibration damps the flow conduit vibration in Z, and that a stiff meter mount raises conduit frequency while a soft meter mount lowers conduit frequency. The change in conduit frequency with mounting stiffness has been observed experimentally in meters with high Y-vibration amplitude. It is a problem because conduit frequency is used to determine fluid density and frequency is also an indication of conduit stiffness. Changes in conduit stiffness due to mounting stiffness change the calibration factor of the meter. The direct coupling between the drive vibration and the local environment also results in an unstable zero (a flow signal when no flow is present) of the meter.

Summary of the Solution

The present invention helps solve the problems associated with unbalanced vibrational forces using a balance system that is sized and located so as to balance out the drive system. Advantageously, in some embodiments the invention can maintain a substantially constant mass flow calibration factor over a wide range of possible flow material densities.

Some examples of a balance system include two or more Y-balance weights and two or more attachment members that couple the two or more Y-balance weights to a flow conduit. At least a first Y-balance weight is coupled to the flow conduit at a first location between the first conduit node and the drive system and at least a second Y-balance weight is coupled to flow conduit at a second location between the drive system and the second conduit node. The two or more Y-balance weights are sized and located such that the combined center of mass of the driver plus the two or more Y-balance weights lies substantially on the X-Y plane of the conduit centerline.

In some examples, two or more balance devices, called active-y-balances, can be configured on the flow conduit(s). An active-y-balance comprises a mass connected to one end of an attachment member, with the other end of the attachment member being attached to the flow conduit between the driver and a bending axis W. Active-y-balances can be used on one or both conduits depending on the locations of the mass centers of the magnet and coil and the type of flow meter configuration (*i.e.*, single or dual conduits).

An active-y-balance works by using the Z-direction conduit motion to move the active-y-balance mass in the Y-direction. The Y-direction momentum of the active-y-balance can be designed to balance the Y-direction momentum of the drive components and to thereby prevent unwanted case and environment motion. By the principle of equivalence, this also makes the meter immune to environmental vibrations and damping.

ASPECTS

An aspect of the invention is a Coriolis flow meter comprising:

at least one flow conduit, with the at least one flow conduit including a first conduit node and a second conduit node and including a bending axis W that intersects the flow conduit at the first conduit node and at the second conduit node, wherein the at least one flow conduit vibrates around the bending axis W;

a drive system coupled to the at least one flow conduit; and

a balance system coupled to the at least one flow conduit, with the balance system comprising two or more Y-balance weights and two or more attachment members that couple the two or more Y-balance weights to the at least one flow conduit, wherein at least a first Y-balance weight is coupled to the at least one flow conduit at a first location between the first conduit node and the drive system and at least a second Y-balance weight is coupled to the at least one flow conduit at a second location between the drive system and the second conduit node.

Preferably the drive system is located a vertical distance Y_d above the bending axis W, the first Y-balance weight is located a vertical distance Y_{w1} above the bending axis W, and the second Y-balance weight is located a vertical distance Y_{w2} above the bending axis W.

Preferably a first ratio Y_d/Y_{w1} is substantially one and one-half.

Preferably a first ratio Y_d/Y_{w1} is substantially equal to a second ratio Y_d/Y_{w2}.

Preferably a first ratio Y_d/Y_{w1} and a second ratio Y_d/Y_{w2} are configured so that a drive frequency versus twist frequency ratio $\omega_{DRIVE}/\omega_{TWIST}$ is substantially constant over changes in fluid density of a flow medium in the at least one flow conduit.

Preferably the two or more Y-balance weights and the two or more attachment members are permanently coupled to the at least one flow conduit.

Preferably the two or more Y-balance weights and the two or more attachment members are removably coupled to the at least one flow conduit.

Preferably the two or more attachment members are at least partially deformable in response to motion of the at least one flow conduit.

Preferably a deformation of the two or more attachment members and the two or more Y-balance weights cause the natural frequency of the balance system to be less than the drive frequency of the flow meter.

Preferably the balance system vibrates substantially out of phase with the at least one flow conduit.

Preferably the balance system is sized and located such that the combined center of mass of the drive system and the balance system lies substantially proximate a plane of the centerline of the at least one flow conduit.

Preferably the balance system is located on the substantially opposite side of the at least one flow conduit from the drive system.

Preferably the balance system is located on the substantially opposite side of the at least one flow conduit from the drive system and at an orientation substantially forty-five degrees to a horizontal plane of the flow conduit.

Preferably the balance system is sized and located such that the momentum of the balance system is substantially equal and substantially opposite to the momentum of the drive system in a direction substantially perpendicular to a drive motion.

Preferably a mass M_{split} of an individual Y-balance weight comprises substantially one-half of a mass of a single, driver-located weight M_{single} multiplied by the cube of a vertical distance Y_d of the drive system above the bending axis W divided by a vertical distance Y_w of the individual Y-balance weight above the bending axis W.

An additional aspect of the invention is a method for force balancing a Coriolis flow meter, the method comprising:

providing at least one flow conduit, with the at least one flow conduit including a first conduit node and a second conduit node and further including a bending axis W that intersects the flow conduit at the first conduit node and at the second conduit node, wherein the at least one flow conduit vibrates around the bending axis W;

providing a drive system coupled to the at least one flow conduit; and

providing a balance system coupled to the at least one flow conduit, with the balance system comprising two or more Y-balance weights and two or more attachment members that couple the two or more Y-balance weights to the at least one flow conduit, wherein at least a first Y-balance weight is coupled to the at least one flow conduit at a first location between the first conduit node and the drive system and at least a second Y-balance weight is coupled to the at least one flow conduit at a second location between the drive system and the second conduit node.

Preferably the drive system is located a vertical distance Y_d above the bending axis W, the first Y-balance weight is located a vertical distance Y_{w1} above the bending axis W, and the second Y-balance weight is located a vertical distance Y_{w2} above the bending axis W.

Preferably a first ratio Y_d/Y_{w1} is substantially one and one-half.

Preferably a first ratio Y_d/Y_{w1} is substantially equal to a second ratio Y_d/Y_{w2}.

Preferably a first ratio Y_d/Y_{w1} and a second ratio Y_d/Y_{w2} are configured so that a drive frequency versus twist frequency ratio $\omega_{DRIVE}/\omega_{TWIST}$ is substantially constant over changes in fluid density of a flow medium in the at least one flow conduit.

Preferably the two or more Y-balance weights and the two or more attachment members are permanently coupled to the at least one flow conduit.

Preferably the two or more Y-balance weights and the two or more attachment members are removably coupled to the at least one flow conduit.

Preferably the two or more attachment members are at least partially deformable in response to motion of the at least one flow conduit.

Preferably a deformation of the two or more attachment members and the two or more Y-balance weights cause the natural frequency of the balance system to be less than the drive frequency of the flow meter.

Preferably the balance system vibrates substantially out of phase with the at least one flow conduit.

Preferably the balance system is sized and located such that the combined center of mass of the drive system and the balance system lies substantially proximate a plane of the centerline of the at least one flow conduit.

Preferably the balance system is located on the substantially opposite side of the at least one flow conduit from the drive system.

Preferably the balance system is located on the substantially opposite side of the at least one flow conduit from the drive system and at an orientation substantially forty-five degrees to a horizontal plane of the flow conduit.

Preferably the balance system is sized and located such that the momentum of the balance system is substantially equal and substantially opposite to the momentum of the drive system in a direction substantially perpendicular to a drive motion.

Preferably a mass M_{split} of an individual Y-balance weight comprises substantially one-half of a mass of a single, driver-located weight M_{single} multiplied by the cube of a vertical distance Y_d of the drive system above the bending axis W divided by a vertical distance Y_w of the individual Y-balance weight above the bending axis W.

Description of the Drawings

FIG. 1 illustrates a Coriolis flow meter comprising a flow meter assembly and meter electronics;

FIG. 2 illustrates a drive system in one embodiment of a Coriolis flow meter;

FIG. 3 illustrates an X-axis section view of a flow conduit of a Coriolis meter;

FIG. 4 illustrates a balance system in a first example of the invention;

FIG. 5 illustrates a balance system in another example of the invention; and

FIG. 6 illustrates a balance system in yet another example of the invention.

Detailed Description of the Invention

FIGS. 1-5 and the following description depict specific examples to teach those skilled in the art how to make and use the best mode of the invention. For the purpose of teaching inventive principles, some conventional aspects have been simplified or omitted. Those skilled in the art will appreciate variations from these examples that fall within the scope of the invention. Those skilled in the art will appreciate that the features described below can be combined in various ways to form multiple variations of the invention. As a result, the invention is not limited to the specific examples described below, but only by the claims and their equivalents.

FIG. 1 illustrates a Coriolis flow meter **5** comprising a flow meter assembly **10** and meter electronics **20**. Meter electronics **20** is connected to meter assembly **10** via leads **100** to provide density, mass flow rate, volume flow rate, totalized mass flow, temperature, and other information over path **26**. It should be apparent to those skilled in the art that the present invention can be used by any type of Coriolis flow meter regardless of the number of drivers, pick-off sensors, flow conduits or the operating mode of vibration.

Flow meter assembly **10** includes a pair of flanges **101** and **101'**; manifolds **102** and **102'**; driver **104**; pick-off sensors **105-105'**; and flow conduits **103A** and **103B**. Driver **104** and pick-off sensors **105** and **105'** are connected to flow conduits **103A** and **103B**. The flow meter assembly 10 can also include a temperature sensor (not shown).

Flanges **101** and **101'** are affixed to manifolds **102** and **102'**. Manifolds **102** and **102'** are affixed to opposite ends of spacer **106**. Spacer **106** maintains the spacing between manifolds **102** and **102'** to prevent undesired vibrations in flow conduits **103A** and **103B**. When flow meter assembly **10** is inserted into a pipeline system (not shown) which carries the material being measured, material enters flow

meter assembly **10** through flange **101**, passes through inlet manifold **102** where the total amount of material is directed to enter flow conduits **103A** and **103B**, flows through flow conduits **103A** and **103B** and back into outlet manifold **102'** where it exits meter assembly **10** through flange **101'**.

Flow conduits **103A** and **103B** are selected and appropriately mounted to inlet manifold **102** and outlet manifold **102'** so as to have substantially the same mass distribution, moments of inertia, and elastic modules about bending axes **W--W** and **W'--W'** respectively. The flow conduits extend outwardly from the manifolds in an essentially parallel fashion.

Flow conduits **103A-B** are driven by driver **104** in opposite directions about their respective bending axes **W** and **W'** and at what is termed the first out-of-phase bending mode of the flow meter. Driver **104** may comprise one of many well known arrangements, such as a magnet mounted to flow conduit **103A** and an opposing coil mounted to flow conduit **103B**. An alternating current is passed through the opposing coil to cause both conduits to oscillate. A suitable drive signal is applied by meter electronics **20**, via lead **110** to driver **104**. The description of **FIG. 1** is provided merely as an example of the operation of a Coriolis flow meter and is not intended to limit the teaching of the present invention.

Meter electronics **20** receives sensor signals on leads **111** and **111'**, respectively. Meter electronics **20** produces a drive signal on lead **110** which causes driver **104** to oscillate flow conduits **103A** and **103B**. Meter electronics **20** processes left and right velocity signals from pick-off sensors **105**, **105'** in order to compute a mass flow rate. Path **26** provides an input and an output means that allows meter electronics **20** to interface with an operator.

FIG. 2 illustrates a drive system **104** in one embodiment of a Coriolis flow meter **5**. In a preferred exemplary embodiment, driver **104** is a coil and magnet assembly. One skilled in the art will note that other types of drive systems may be used.

Driver **104** has a magnet assembly **210** and a coil assembly **220**. Brackets **211** extend outward in opposing directions from magnet assembly **210** and coil assembly **220**. Brackets **211** are wings which extend outward from the flat base and have a substantially curved edge **290** on a bottom side that is formed to receive a flow conduit **103A** or **103B**. The curved edge **290** of brackets **211** are then welded

or in some other manner affixed to flow conduits **103A** and **103B** to attach driver **104** to Coriolis flow meter **5**.

Magnet assembly **210** has a magnet keeper **202** as a base. Brackets **211** extend from a first side of magnet keeper **202**. Walls **213** and **214** extend outward from outer edges of a second side of magnet keeper **202**. Walls **213** and **214** control the direction of the magnetic field of magnet **203** perpendicular to the windings of coil **204**.

Magnet **203** is a substantially cylindrical magnet having a first and a second end. Magnet **203** is fitted into a magnet sleeve (not shown). The magnet sleeve and magnet **203** are affixed to a second surface of magnet keeper **202** to secure magnet **203** in magnet assembly **210**. Magnet **203** typically has a pole (not shown) affixed to its second side. The magnet pole (not shown) is a cap that is fitted to the second end of magnet **203** to direct the magnetic fields into coil **204**.

Coil assembly **220** includes coil **204**, and coil bobbin **205**. Coil bobbin **205** is affixed to a bracket **211**. Coil bobbin **205** has a spool protruding from a first surface around which coil **204** is wound. Coil **204** is mounted on coil bobbin **205** opposing magnet **203**. Coil **204** is connected to lead **110** which applies alternating currents to coil **204**. The alternating currents cause coil **204** and magnet **203** to attract and repel one another which in turn causes flow conduits **103A** and **103B** to oscillate in opposition to one another.

FIG. 3 illustrates a simplified X-axis section view of flow conduit **103**. Flow conduit **103** has mounted to it driver **104**. Driver **104** is offset from flow conduit **103** by **Φ**. Flow conduit **103** moves in the Z-direction with an amplitude **ΔZ**. As flow conduit **103** translates in the Z-direction its fixed location causes it to rotate about its center of rotation, **CR**, resulting in angular amplitude, **Δθ**. Driver **104** and its associated center of mass, **CM**, rotates with the same angular amplitude, **Δθ**, as flow conduit **103**. However, because of the offset angle, **Φ**, drive component center of mass **CM** oscillates up and down line **L**. This gives drive component center of mass **CM** vertical motion ΔY_m.

FIG. 4 illustrates a balance system **400** in a first example of the invention. Balance system **400** includes Y-balance weights **401 & 402** coupled to flow conduits **103A & B**. Coupling of Y-balance weights **401& 402** can be accomplished using various methods including mechanical attachment, welding, brazing, or gluing. Y-balance weight **401** has a center of mass CM_{b1}. Y-balance

weight **401** is sized and located such that its center of mass $\mathbf{CM_{b1}}$ combined with the coil assembly center of mass $\mathbf{CM_c}$ results in a combined center of mass $\mathbf{CCM_1}$ that is located on the X-Y plane of conduit **103A**. Also, Y-balance weight **402** has a center of mass $\mathbf{CM_{b2}}$. Y-balance weight **402** is sized and located such that its center of mass $\mathbf{CM_{b2}}$ combined with the magnet assembly center of mass $\mathbf{CM_m}$ results in a combined center of mass $\mathbf{CCM_2}$ that is located on the X-Y plane of conduit **103B**. The particular attributes of the Y-balance weights are such that the mass times velocity of the Y-balance weight is equal and opposite to the mass times velocity of the driver assembly, in the Y-direction, for each flow conduit as shown by:

$$(M * V_Y)_{BW} + (M * V_Y)_{DA} = 0 \qquad (3)$$

In other words the momentum of the Y-balance weight counters the momentum of the driver assembly attached to a particular conduit as given by:

$$(M_{BW})_Y + (M_{DA})_Y = 0 \qquad (4)$$

FIG. 5 illustrates balance system **500** in another example of the invention. Balance system **500** includes Y-balance weights **501 & 502** coupled to flow conduits **103A & B** using leaf springs **504 & 505**. Leaf spring **504** in this embodiment is oriented at approximately 45 degrees to the X-Y plane and is connected to the opposite side of the flow conduit as coil assembly **220**. The stiffness of leaf spring **504** and mass of Y-balance weight **501** are chosen so that the natural frequency of the active-y-balance in its first vibration mode (the diving board mode) is below the drive frequency of the meter. With the natural frequency below the excitation (drive) frequency, weight **501** tends to move out of phase with conduit **103A**. Thus, as conduit **103A** moves to the left (-Z direction), active-Y-balance weight **501** moves to the right (+Z) relative to the conduit. But, because of the angle of leaf spring **504** to the X-Y plane, weight **501** is constrained by leaf spring **504** to move to the right and down (+Z and -Y). This is advantageous because when conduit **103A** moves to the left, the offset coil assembly **220** moves left and up (+Z and +Y). By designing mass and spring rate such that the Y-direction momentum (mass times velocity) of the active-y-balance are equal and

opposite to the Y-direction momentum of the offset driver components, the external Y-direction vibration of the entire meter can be nearly eliminated. The same design principles apply to tube **103B**.

This second example has an additional advantage. Because weight **501** and **502** are suspended from conduits **103A & B** by leaf spring **504 & 505**, they vibrate out of phase with flow conduits **103A & B**, resulting in very little of its mass being coupled to flow conduits **103A & B**.

It should be understood that the angle and orientation of the leaf springs 504 and weights 501 in the figure are given for example. The angle and orientation of the leaf springs 504 and weights 501 can be varied and still achieve the goals of the invention.

FIG. 6 illustrates a balance system **600** in yet another example of the invention. In this embodiment, the balance system **600** includes the flow conduit **103** having a first conduit node **603a** and a second conduit node **603b**, the drive system **104**, pickoffs **105** and **105'**, at least first and second Y-balance weights **601a** and **601b**, and at least first and second attachment members **602a** and **602b**. The pickoffs **105** and **105'** are located between the drive system **104** and the first conduit node **603a** and the second conduit node **603b**. It should be understood that the shape of the flow conduit 103 in the figure is given for example, and the flow conduit 103 can comprise other geometries. It should also be understood that the locations of the Y-balance weights 601a and 601b are also examples, and the locations can vary according to the flow tube material, the flow tube geometry, the flow material, temperature, driver vibration, driver mass, pick-off mass, construction tolerances, etc.

The flow conduit **103** can comprise a single conduit flow meter or can comprise a component of a two conduit flow meter (see FIG. 5). The flow conduit **103** vibrates around a bending axis W (see also the center of rotation CR in FIG. 3). The bending axis W intersects the flow conduit at the first conduit node **603a** and at the second conduit node **603b**.

The Y-balance weights **601** and attachment members **602** are coupled to the flow conduit **103**. A first Y-balance weight **601a** and a first attachment member **602a** can be coupled to the flow conduit **103** between the first conduit node **603a** and the drive system **104**. Likewise, a second Y-balance weight **601b** and a second attachment member **602b** can be coupled to the flow conduit **103** between

the drive system **104** and the second conduit node **603b**. The first Y-balance weight **601a** and the second Y-balance weight **601b** can be permanently or removably coupled to the flow conduit **103** by the corresponding first attachment member **602a** and second attachment member **602b**. In addition, a removably coupled attachment member **602** can comprise a slidably coupled attachment member **602** that can be slidably positioned on the flow conduit **103**.

Two or more Y-balance weights **601** are used in order to accurately and effectively perform Y-balancing of the flow meter **5**, but without affecting a flow calibration characteristic of the flow meter **5**. A problem that is encountered with a single Y-balance weight, attached at a single point on the flow conduit **103**, is that the flow calibration factor can shift when the flow meter **5** is used for fluids of different densities. In order for the flow meter **5** to have a flow calibration factor that is independent of fluid density, the distribution of mass added to the flow conduit **103** has to be such that a drive frequency to twist frequency ratio (*i.e.*, $\omega_{DRIVE}/\omega_{TWIST}$) remains constant over any and all changes in fluid density.

In a typical U-tube flow meter, the flow conduit **103** is vibrated at a drive frequency. The drive frequency is chosen to substantially match a resonant frequency of the flow conduit **103**. The resulting drive mode vibration (*i.e.*, a first out-of-phase bending mode) includes stationary nodes at the ends of the flow conduit **103**, while the point of maximum vibrational amplitude occurs at the center of the flow conduit **103**, *i.e.*, at the drive system **104**. For example, these end nodes can comprise the nodes **603a** and **603b** shown in FIG. 6.

The twist mode of vibration is excited by the Coriolis force resulting from fluid flow. It is the tube vibration in the twist mode that creates the time delay that is measured by the electronics. In a twist mode of vibration (*i.e.*, a second out-of-phase bending mode), the flow conduit **103** has stationary nodes at the ends of the flow conduit and additionally includes a stationary node at the center (*i.e.*, at the drive system 104). Consequently, in the twist mode the maximum amplitude of the flow conduit 103 occurs at two points located between the drive system 104 and the end nodes.

The twist mode has a twist resonant frequency that is generally higher than the drive frequency. However, the Coriolis force is of greatest amplitude at the drive frequency, rather than the higher twist frequency, and is preferably measured at the drive frequency. The resonant frequency of the twist mode of vibration is

generally higher than the resonant frequency of the drive mode of vibration. Therefore, the resulting amplitude of vibration is a function of the frequency difference between the drive frequency and the twist resonant frequency. If the two frequencies are close, the twist amplitude is large. If they are distant, the twist amplitude is small. It can thus be seen that a frequency ratio between the drive frequency and the twist resonant frequency must be kept constant in order to keep the flow calibration factor of the flow meter at a constant level.

The drive and twist frequencies both change when the fluid density changes. The location of mass on the flow tube determines whether the frequency ratio remains constant between the two. Because the drive mode in a typical U-tube flow meter includes nodes at the ends of the flow conduit **103** and because the point of maximum amplitude occurs in the center, locating extra mass at the drive system **104** has the effect of lowering the drive frequency and reducing the effect of fluid density change on the drive frequency. In the twist mode, where there are nodes at both ends of each flow tube as well as one in the center, locating extra mass at the drive system **104** does not affect the twist mode because of the central node. However, locating mass at the points of maximum deflection in the twist mode (between the drive system **104** and the end nodes) reduces the twist mode sensitivity to changes in fluid density.

The solution to this drawback is to form a balance system **600** including at least two spaced apart Y-balance weights **601** on either side of the drive system **104**. The at least two Y-balance weights **601** are located upstream and downstream from the drive system **104**, as shown in the figure. The mass for the Y-balance weights can thus be located at a distance from the drive system **104** so that the drive and twist frequencies both change the proper amount with changes in fluid density. This distance from the drive system **104** can be determined, such as through finite element analysis, for example, and has been determined to be the distance at which the ratio of frequencies ($\omega_{DRIVE}/\omega_{TWIST}$) stays constant with changes in fluid density. Simultaneously, these weights can be sized so that they are correct for Y-balancing the meter.

The drive system **104** is located a vertical distance Y_d above the bending axis W. The first Y-balance weight **601a** is located a vertical distance Y_{w1} above the bending axis W. The second Y-balance weight **601b** is located a vertical distance Y_{w2} above the bending axis W. The two or more Y-balance weights **601a**

and **601b** are therefore located according to a Y distance ratio Y_d/Y_{w1} and Y_d/Y_{w2}, for example. In one embodiment, one or both of the ratios can be substantially one and one-half (*i.e.*, $Y_d/Y_w = 1\ ½$). In another embodiment having a different flow tube geometry (and other factors), the ratios can be substantially two. However, other values can be used as desired. In one embodiment, the first ratio Y_d/Y_{w1} is substantially equal to the second ratio Y_d/Y_{w2} (*i.e.*, $Y_d/Y_{w1} = Y_d/Y_{w2}$). However, it should be understood that the distances can vary according to flow conduit size and characteristics, construction tolerances, etc., and the distances therefore can form any size of ratio. Moreover, the two ratios Y_d/Y_{w1} and Y_d/Y_{w2} can differ, and are not necessarily equal.

The actual locations of the Y-balance weights **601**, and therefore the distances Y_{w1} and Y_{w2}, can be determined experimentally or can be iteratively determined using a Finite Element Analysis (FEA) technique, for example. The desired FEA result maintains a substantially constant $\omega_{DRIVE}/\omega_{TWIST}$ ratio over changes in fluid density of a flow medium in the flow conduit **103**. The desired FEA therefore constrains the Y-motion to an acceptable level. In one embodiment, an approximate starting point for the FEA computation initially locates the Y-balance weights **601** half-way vertically to the pickoffs **105** and **105'** (*i.e.*, the distance ratios Y_d/Y_{w1} and Y_d/Y_{w2} are approximately = 2 and creates an angle from the horizontal that is approximately 45 degrees).

In addition, the mass of each Y-balance weight **601** will have to be calculated when the location has been determined. The mass M_{split} of each individual split Y-balance weight **601** will need to be greater than the mass M_{single} of a single Y-balance weight located at the drive system **104** in order to achieve the same mass balancing effect. The mass M_{split} of an individual Y-balance weight **601a** or **601b** can be approximately determined through use of the formula:

$$M_{split} = ½(M_{single})(Y_d/Y_w)^3 \qquad (5)$$

Consequently, as the vertical distance Y_w decreases, the above formula will cause the mass M_{split} to increase.

As in the previously discussed Y-balance weight **501** and leaf spring **504** of FIG. 5, the attachment members **602a** and **602b** can be at least partially deformable. For example, an attachment member **602** can comprise a spring or leaf spring. Consequently, the attachment members **602a** and **602b** can deform in

response to motion of the flow conduit **103**. The deformation of the two or more attachment members **602** and the two or more Y-balance weights **601** cause the natural frequency of the balance system **600** to be less than the drive frequency of the flow meter **5**. As a result, the balance system **600** can vibrate out of phase with the flow conduit **103**.

The balance system **600** in one embodiment is sized and located such that the combined center of mass of the drive system **104** and the balance system **600** lies substantially proximate a plane of the centerline of the flow conduit **103**. In one embodiment, the balance system **600** is located on the substantially opposite side of the flow conduit **103** from the drive system **104** (see FIG. 5). In one embodiment, the balance system **600** is located on the substantially opposite side of the flow conduit **103** from the drive system **104** and at an orientation substantially forty-five degrees to a horizontal plane of the flow conduit **103**. The balance system **600** in one embodiment is sized and located such that the momentum of the balance system **600** is substantially equal and opposite to the momentum of the drive system **104** in a direction substantially perpendicular to a drive motion.

It should be understood that more than two Y-balance weights **601** can be used in order to accomplish the objectives of the invention. In addition, various numbers and configurations of attachment members **602** can be employed. The attachment members **602** can include cross-links between Y-balance weights **601**, can include multiple attachment members **602** per Y-balance weight **601**, can include variously shaped or sized attachment members **602**, can include attachment members **602** formed of different materials, can include attachment members **602** having different deformation characteristics, etc.

The above examples are not limited to compensating for the driver mass offset. For instance, deformation of the manifold castings by conduit forces can cause the meter flanges to vibrate in the Y-direction. If this flange vibration is in-phase with that caused by the drive mass offset, then the balance mass can be increased to compensate for the additional vibration due to the manifold deformation. Likewise, if the flange vibration due to manifold deformation is out-of-phase with that caused by the drive mass offset, the balance mass can be made smaller.

CLAIMS

What is claimed is:

1. A Coriolis flow meter comprising:

at least one flow conduit (103), with the at least one flow conduit (103) including a first conduit node (603a) and a second conduit node (603b) and including a bending axis W that intersects the flow conduit (103) at the first conduit node (603a) and at the second conduit node (603b), wherein the at least one flow conduit (103) vibrates around the bending axis W;

a drive system (104) coupled to the at least one flow conduit (103); and

a balance system (600) coupled to the at least one flow conduit (103), with the balance system (600) comprising two or more Y-balance weights (601a, 601b) and two or more attachment members (602a, 602b) that couple the two or more Y-balance weights (601a, 601b) to the at least one flow conduit (103), wherein at least a first Y-balance weight (601a) is coupled to the at least one flow conduit (103) at a first location between the first conduit node (603a) and the drive system (104) and at least a second Y-balance weight (601b) is coupled to the at least one flow conduit (103) at a second location between the drive system (104) and the second conduit node (603b).

2. The Coriolis flow meter of claim 1 wherein the drive system (104) is located a vertical distance Y_d above the bending axis W, wherein the first Y-balance weight (601a) is located a vertical distance Y_{w1} above the bending axis W, and wherein the second Y-balance weight (601b) is located a vertical distance Y_{w2} above the bending axis W.

3. The Coriolis flow meter of claim 2 wherein a first ratio Y_d/Y_{w1} is substantially one and one-half.

4. The Coriolis flow meter of claim 2 wherein a first ratio Y_d/Y_{w1} is substantially equal to a second ratio Y_d/Y_{w2}.

5. The Coriolis flow meter of claim 2 wherein a first ratio Y_d/Y_{w1} and a second ratio Y_d/Y_{w2} are configured so that a drive frequency versus twist frequency ratio $\omega_{DRIVE}/\omega_{TWIST}$ is substantially constant over changes in fluid density of a flow medium in the at least one flow conduit (103).

6. The Coriolis flow meter of claim 1 wherein the two or more Y-balance weights (601a, 601b) are located at points of maximum deflection of the at least one conduit (103) in a twist mode.

7. The Coriolis flow meter of claim 1 wherein the two or more Y-balance weights (601a, 601b) and the two or more attachment members (602a, 602b) are permanently coupled to the at least one flow conduit (103).

8. The Coriolis flow meter of claim 1 wherein the two or more Y-balance weights (601a, 601b) and the two or more attachment members (602a, 602b) are removably coupled to the at least one flow conduit (103).

9. The Coriolis flow meter of claim 1 wherein the two or more attachment members (602a, 602b) are at least partially deformable in response to motion of the at least one flow conduit (103).

10. The Coriolis flow meter of claim 1 wherein a deformation of the two or more attachment members (602a, 602b) and the two or more Y-balance weights (601a, 601b) cause the natural frequency of the balance system (600) to be less than the drive frequency of the flow meter.

11. The Coriolis flow meter of claim 1 wherein the balance system (600) vibrates substantially out of phase with the at least one flow conduit (103).

12. The Coriolis flow meter of claim 1 wherein the balance system (600) is sized and located such that the combined center of mass of the drive system (104) and the balance system (600) lies substantially proximate a plane of the centerline of the at least one flow conduit (103).

13. The Coriolis flow meter of claim 1 wherein the balance system (600) is located on the substantially opposite side of the at least one flow conduit (103) from the drive system (104).

14. The Coriolis flow meter of claim 1 wherein the balance system (600) is located on the substantially opposite side of the at least one flow conduit (103) from the drive system (104) and at an orientation substantially forty-five degrees to a horizontal plane of the flow conduit (103).

15. The Coriolis flow meter of claim 1 wherein the balance system (600) is sized and located such that the momentum of the balance system (600) is substantially equal and substantially opposite to the momentum of the drive system (104) in a direction substantially perpendicular to a drive motion.

16. The Coriolis flow meter of claim 1 wherein a mass M_{split} of an individual Y-balance weight (601) comprises substantially one-half of a mass of a single, driver-located weight M_{single} multiplied by the cube of a vertical distance Y_d of the drive system (104) above the bending axis W divided by a vertical distance Y_w of the individual Y-balance weight (601) above the bending axis W.

17. A method for force balancing a Coriolis flow meter, the method comprising:

providing at least one flow conduit (103), with the at least one flow conduit (103) including a first conduit node (603a) and a second conduit node (603b) and further including a bending axis W that intersects the flow conduit (103) at the first conduit node (603a) and at the second conduit node (603b), wherein the at least one flow conduit (103) vibrates around the bending axis W;

providing a drive system (104) coupled to the at least one flow conduit (103); and

providing a balance system (600) coupled to the at least one flow conduit (103), with the balance system (600) comprising two or more Y-balance weights (601a, 601b) and two or more attachment members (602a, 602b) that couple the two or more Y-balance weights (601a, 601b) to the at least one flow conduit (103), wherein at least a first Y-balance weight (601a) is coupled to the at least one flow conduit (103) at a first location between the first conduit node (603a) and the drive

system (104) and at least a second Y-balance weight (601b) is coupled to the at least one flow conduit (103) at a second location between the drive system (104) and the second conduit node (603b).

18. The method of claim 17 wherein the drive system (104) is located a vertical distance Y_d above the bending axis W, wherein the first Y-balance weight (601a) is located a vertical distance Y_{w1} above the bending axis W, and wherein the second Y-balance weight (601b) is located a vertical distance Y_{w2} above the bending axis W.

19. The method of claim 18 wherein a first ratio Y_d/Y_{w1} is substantially one and one-half.

20. The method of claim 18 wherein a first ratio Y_d/Y_{w1} is substantially equal to a second ratio Y_d/Y_{w2}.

21. The method of claim 18 wherein a first ratio Y_d/Y_{w1} and a second ratio Y_d/Y_{w2} are configured so that a drive frequency versus twist frequency ratio $\omega_{DRIVE}/\omega_{TWIST}$ is substantially constant over changes in fluid density of a flow medium in the at least one flow conduit (103).

22. The method of claim 17 wherein the two or more Y-balance weights (601a, 601b) are located at points of maximum deflection of the at least one conduit (103) in a twist mode.

23. The method of claim 17 wherein the two or more Y-balance weights (601a, 601b) and the two or more attachment members (602a, 602b) are permanently coupled to the at least one flow conduit (103).

24. The method of claim 17 wherein the two or more Y-balance weights (601a, 601b) and the two or more attachment members (602a, 602b) are removably coupled to the at least one flow conduit (103).

25. The method of claim 17 wherein the two or more attachment members (602a, 602b) are at least partially deformable in response to motion of the at least one flow conduit (103).

26. The method of claim 17 wherein a deformation of the two or more attachment members (602a, 602b) and the two or more Y-balance weights (601a, 601b) cause the natural frequency of the balance system (600) to be less than the drive frequency of the flow meter.

27. The method of claim 17 wherein the balance system (600) vibrates substantially out of phase with the at least one flow conduit (103).

28. The method of claim 17 wherein the balance system (600) is sized and located such that the combined center of mass of the drive system (104) and the balance system (600) lies substantially proximate a plane of the centerline of the at least one flow conduit (103).

29. The method of claim 17 wherein the balance system (600) is located on the substantially opposite side of the at least one flow conduit (103) from the drive system (104).

30. The method of claim 17 wherein the balance system (600) is located on the substantially opposite side of the at least one flow conduit (103) from the drive system (104) and at an orientation substantially forty-five degrees to a horizontal plane of the flow conduit (103).

31. The method of claim 17 wherein the balance system (600) is sized and located such that the momentum of the balance system (600) is substantially equal and substantially opposite to the momentum of the drive system (104) in a direction substantially perpendicular to a drive motion.

32. The method of claim 17 wherein a mass M_{split} of an individual Y-balance weight (601) comprises substantially one-half of a mass of a single, driver-located weight M_{single} multiplied by the cube of a vertical distance Y_d of the drive system (104) above the bending axis W divided by a vertical distance Y_w of the individual Y-balance weight (601) above the bending axis W.

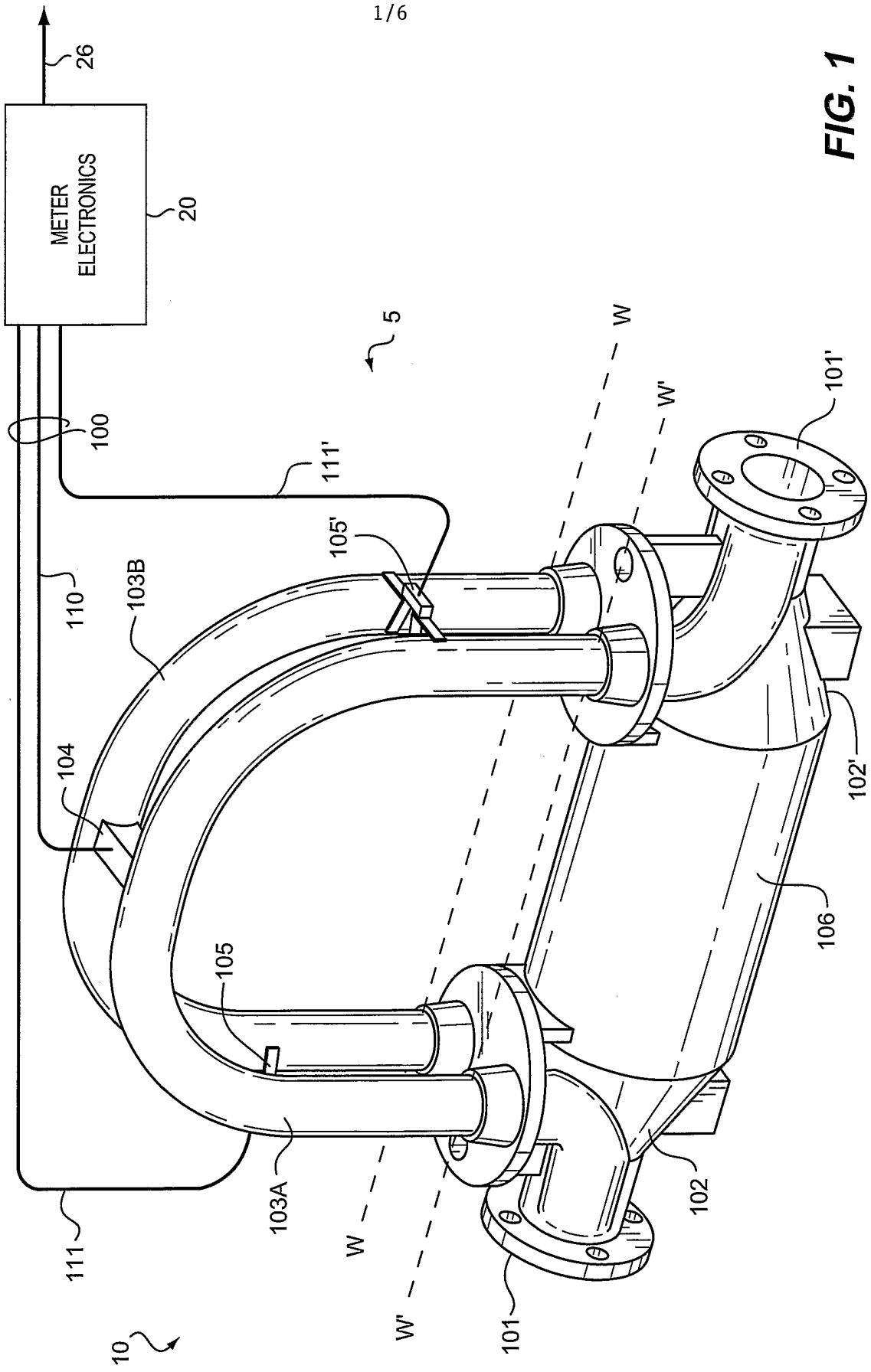
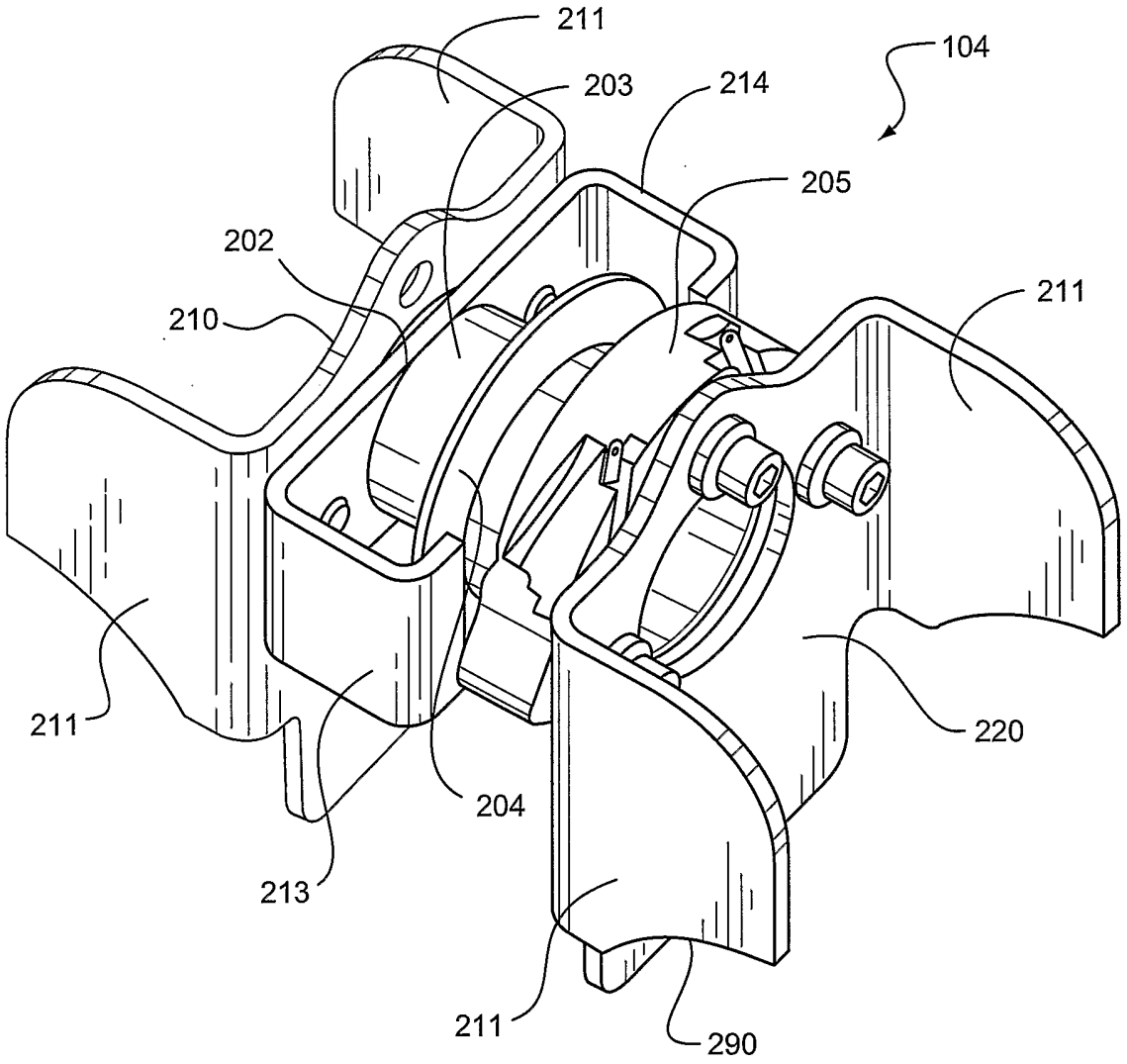

26
METER ELECTRONICS
20
5
W
W'
101'
100
111'
105'
110
103B
104
102'
106
105
103A
102
111
W
W'
101
10

FIG. 1

FIG. 2



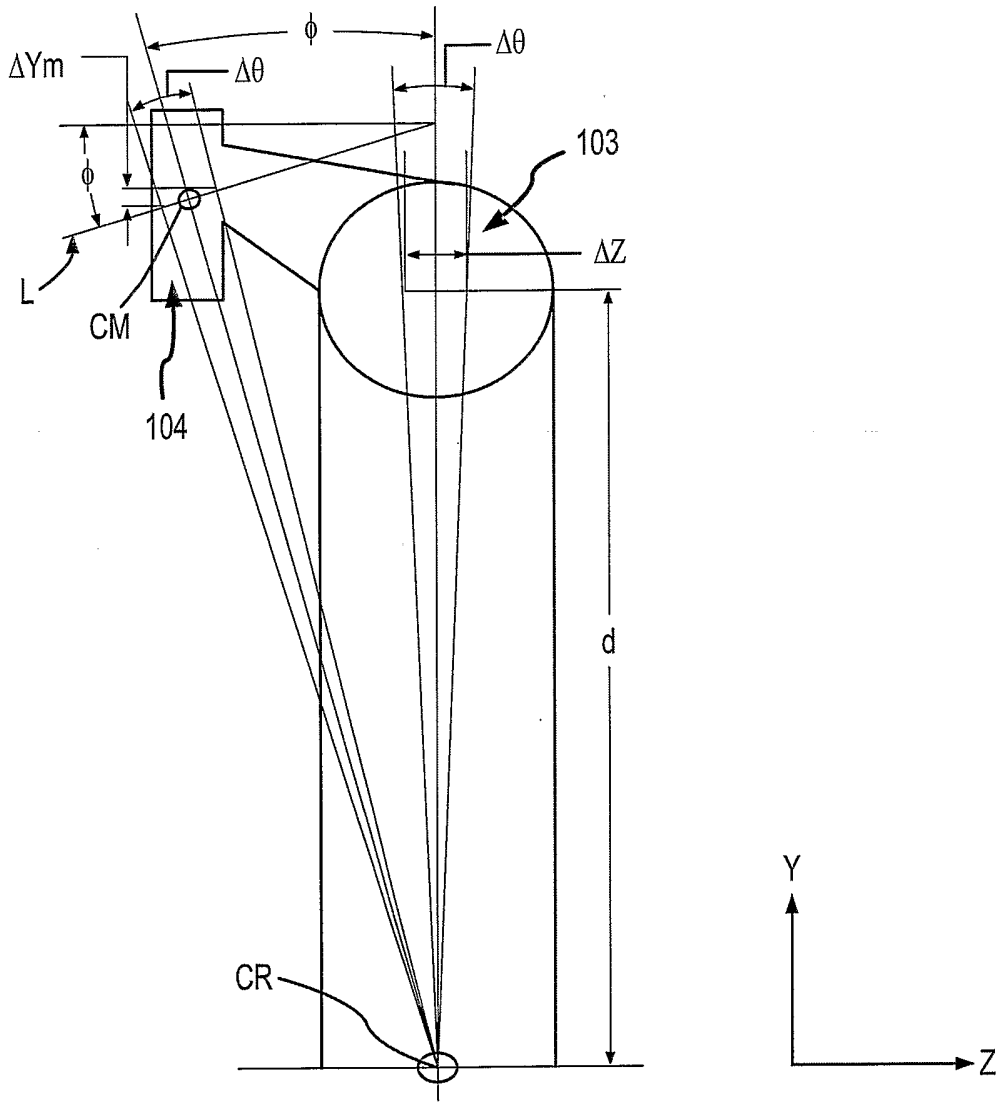


FIG. 3

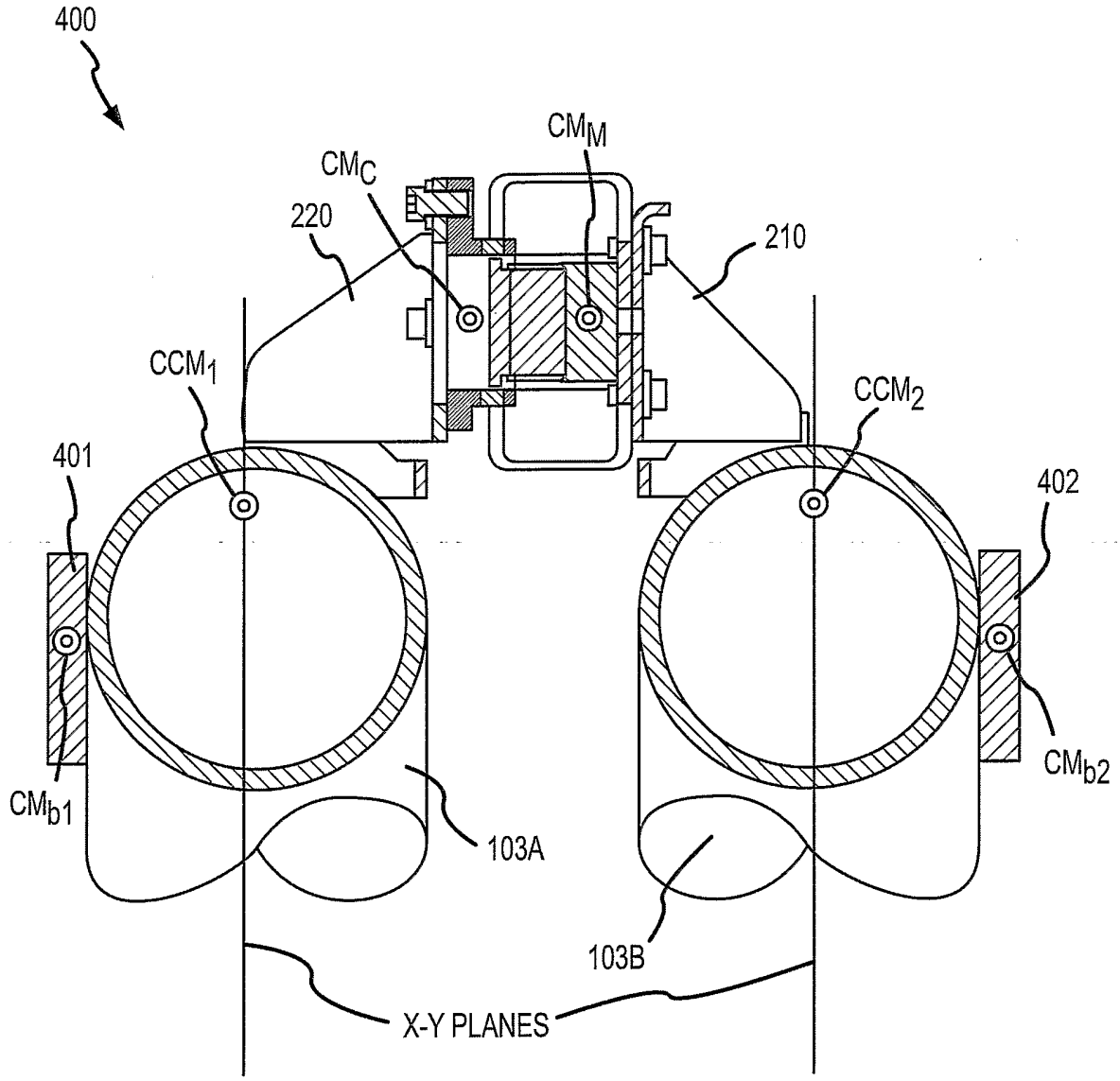

400
CM_M
CM_C
220
210
CCM_1
CCM_2
401
402
CM_b1
CM_b2
103A
103B
X-Y PLANES

FIG. 4

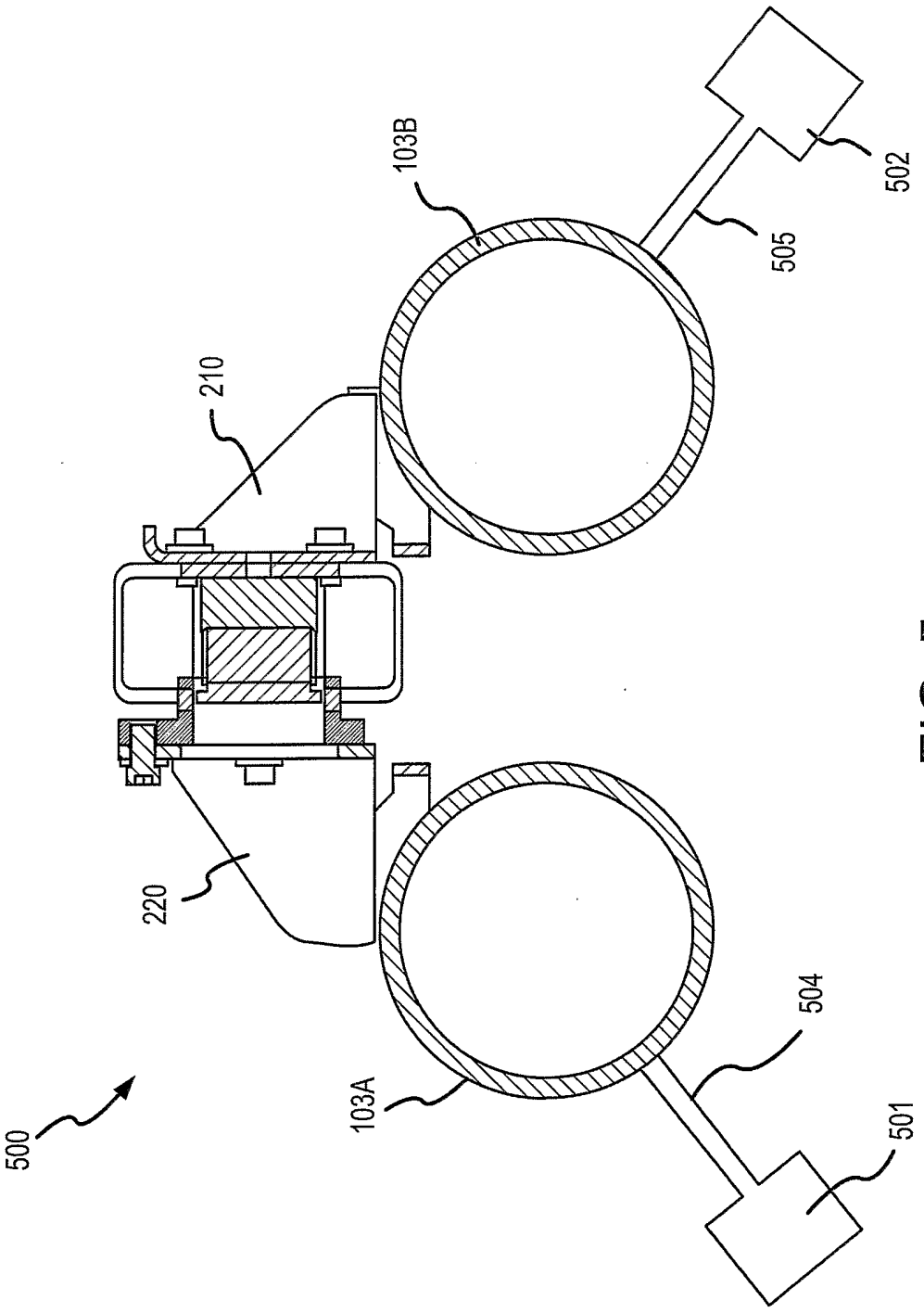


FIG. 5

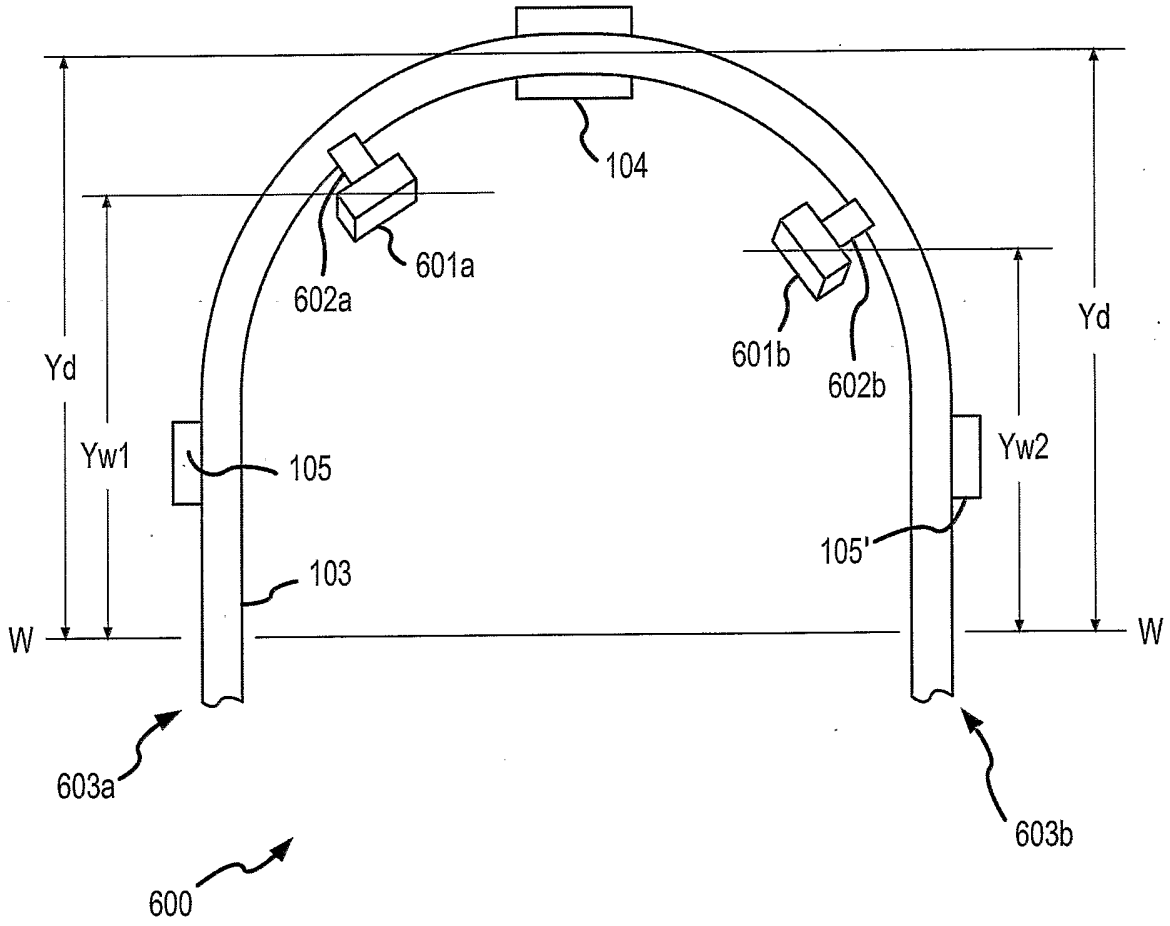

104
601a
602a
601b
602b
Yd
Yw1
105
103
W
105'
Yw2
Yd
W
603a
603b
600

FIG. 6

INTERNATIONAL SEARCH REPORT

Inté onal Application No
PCT/US2004/021318

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01F1/84

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 7 G01F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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X	US 4 831 885 A (DAHLIN) 23 May 1989 (1989-05-23) column 6, line 27 - line 32 column 13 - column 14 column 15, line 54 - line 55 column 17 - column 18 column 24, line 25 - line 38 figures 1,3a,3b,7a,7b,10c	1,2, 5-18, 21-32

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
9 May 2005	17/05/2005

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Barthélemy, M

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INTERNATIONAL SEARCH REPORT

Inte[illegible]nal Application No
PCT/US2004/021318

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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INTERNATIONAL SEARCH REPORT

.....rmation on patent family members

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