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(71) Applicant *(for all designated States except US)*: **MALEMA ENGINEERING CORPORATION** [US/US]; 1060 South Rogers Circle, Boca Raton, FL 33487 (US).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: **YOUNG, Alan, M.** [US/US]; c/o Malema Engineering Corporation, 1060 South Rogers Circle, Boca Raton, FL 33487 (US). **LIN, Jianren** [CN/US]; c/o Malema Engineering Corporation, 1060 South Rogers Circle, Boca Raton, FL 33487 (US). **KNUDSEN, Claus, W.** [DK/US]; c/o Malema Engineering Corporation, 1060 South Rogers Circle, Boca Raton, FL 33487 (US).

(74) Agents: **ZHANG, Jie** et al.; Fenwick & West LLP, Silicon Valley Center, 801 California Street, Mountain View, CA 94041 (US).

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(54) **Title**: METHODS OF MANUFACTURING AND TEMPERATURE CALIBRATING A CORIOLIS MASS FLOW RATE SENSOR

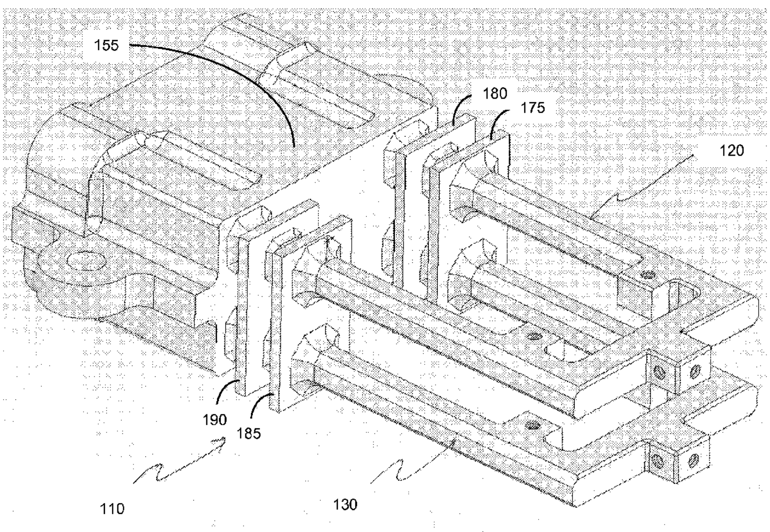

Figure 1

(57) **Abstract**: A subassembly of a Coriolis flowmeter is fabricated from a single monolithic piece of elastic polymeric material. The subassembly includes two flow-sensitive members and a base integrally connected to the two flow-sensitive members. The two flow-sensitive members include straight sections, and are substantially similar and parallel to each other. Flow passages are drilled along the straight sections of the two flow-sensitive members, and drilled entrances are sealed using the elastic polymeric material. A temperature sensor is fixedly attached to a flow-sensitive member for measuring a temperature of the flow-sensitive member and communicating the temperature to a metering electronics. The metering electronics determines a calibrated flow rate of fluid flowing through the Coriolis flowmeter that accounts for the temperature.

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METHODS OF MANUFACTURING AND TEMPERATURE CALIBRATING A CORIOLIS MASS FLOW RATE SENSOR

Inventors: Alan M. Young, Jianren Lin and Claus W. Knudsen

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of United States Provisional Application No. 61/304,228, "METHODS OF MANUFACTURING AND TEMPERATURE CALIBRATING A CORIOLIS MASS FLOW RATE SENSOR" by Alan M. Young, Jianren Lin, and Claus W. Knudsen, filed on February 12, 2010, the content of which is hereby incorporated by reference in its entirety.

FIELD OF THE INVENTION

[0002] The present invention relates generally to fluid mass flow rate and density measuring apparatus based on the Coriolis-effect and in particular, methods for fabricating and calibrating an improved Coriolis flow rate sensor constructed from an elastic polymeric material (e.g., PFA - perfluoroalkoxy copolymer).

DESCRIPTION OF PRIOR ART

[0003] It is well known that Coriolis mass flowmeters can be used to measure the mass flow rate (as well as other properties) of a fluid flowing through a pipeline. Traditional Coriolis flowmeters employ various configurations of one or two tubes that are oscillated in a controlled manner allowing measurement of Coriolis induced deflections (or the effects of such deflections on the tube(s)) as an indication of fluid mass flow rate flowing through the sensor. As expressed in US Patent No. 7,127,815 B2 (col. 2, lines 5-25), much of the Coriolis flowmeter prior art is concerned with using metal flow tubes as the flow-sensitive element, but the prior art also suggests that plastic may be substituted for metal. The '815 patent states that "the mere assertion that a flowmeter could be made out of plastic is nothing more than the abstraction that plastic can be substituted for metal. It does not teach how a plastic flowmeter can be manufactured to generate accurate information over a useful range of operating conditions." Similar statements are found in US Patent No. 6,776,053 B2 (Col. 1, lines 58-68 and Col. 2, lines 1-10).

[0004] The '815 and '053 patents describe methods of fabricating a Coriolis flowmeter with at least one PFA tube attached to a metal base using a cyanoacrylate adhesive. Fundamental to the successful operation of any Coriolis flowmeter is that the flow sensitive element (e.g., a tube in the '815 and '053 patents) must be fixedly attached to a metal base (or manifold) in such a manner that a fixed, stable and unchanging boundary condition is established for the ends of the vibrating sensitive element. For example, the '053 patent states in Claim 1 (Col. 14, lines 65-67) that "... end portions of said flow tube apparatus coupled to said base to create stationary nodes at said end portions...". However, a shortcoming of the '053 and '815 patents is that under normal operating conditions the integrity of the coupling of the tube to the metal base is not necessarily unyielding and unchanging. Rather, it could deteriorate over time from continuous vibration of the tube causing the adhesive joint to crack or otherwise degrade. Additionally, differential thermal expansion/contraction between the different materials of construction (e.g., the tube, the cyanoacrylate adhesive and the metal base) will impair the integrity of the coupling of the tube to the metal base creating an unstable boundary condition resulting in uncontrolled vibration characteristics to such an extent that performance of the device would be compromised.

[0005] The '815 and '053 patents describe properties of PFA tubing which, by its method of manufacture (i.e., extrusion) inherently has bends or curvature that must be eliminated prior to manufacturing a flowmeter (e.g., see '815, Col. 3, lines 42-55). According to the '815 and '053 patents, this problem can be alleviated by subjecting the PFA tubing to an annealing process (see '815, col. 3, lines 30-41) in order to straighten the tube prior to fabricating a flowmeter.

[0006] To facilitate binding of the cyanoacrylate adhesive to the PFA tube, the tubing must be subjected to etching (a process referred to in the '815 patent) that requires submersing and gently agitating PFA tubes in a heated bath containing glycol diether. However, these annealing and etching processes add cost and complexity to the fabrication of the flowmeter and may not necessarily yield tubing suitable for flowmeter fabrication on a consistent basis.

[0007] US Patent No. 6,450,042 B1, US Patent No. 6,904,667 B2 and US Patent Application Publication No. 20020139199 A1 describe methods of fabricating a Coriolis flowmeter via injection molding and forming the flow path from a core mold made from a low-melting point fusible metal alloy containing a mixture of Bismuth, Lead, Tin, Cadmium, and Indium with a melting point of about 47 degrees Celsius. The '042 patent asserts (Col. 2, lines 65-67) that "... with the possible exception of a driver and pick offs, and case, the entirety of the flowmeter is formed by injection molding (emphasis added)." However, this method of fabrication presents significant problems and limitations. During the injection molding process, hot plastic is injected into a mold at temperatures that can exceed 350 degrees Celsius at pressures exceeding 5000 psi. When fabricating thin-wall or small diameter flow passageways (e.g., 4mm diameter; wall thickness < 2mm) such melt temperatures and pressures will likely distort the comparatively narrow (and flexible) fusible metal core (possibly melting its surface) resulting in deformation and contamination of the flow passageways to such an extent that the device could be rendered unusable. In semiconductor, pharmaceutical, bio-pharmaceutical (or other critical high-purity process applications) it is important to avoid metallic contamination however infinitesimal. However, unlike a solid core (e.g., stainless steel), the comparatively soft fusible core could partially melt or abrade during the injection molding process allowing metal atoms to mix and become embedded within the injected plastic permanently contaminating the flow passageway rendering the device unsuitable for high-purity applications.

[0008] In plastic injection molding processes, it is generally recommended that molded features have a similar thickness because otherwise the molded part may not form properly. With reference to the ‘042 patent, this requirement means that all structural features of the Coriolis flowmeters described therein, namely the tube wall, “brace bars”, inlet and outlet flanges, manifold walls,…etc., must all have a similar thickness. However, a consequence of forming the entirety of the flowmeter by injection molding could result in structural and/or dynamic design limitations or compromises that could adversely affect and/or limit flowmeter performance.

[0009] The “spring constant” of a tube material (which is proportional to Youngs Modulus) varies with temperature and directly affects the accuracy of a Coriolis flowmeter. To maintain flow rate measurement accuracy, Coriolis flowmeters require temperature compensation as the fluid and/or ambient temperature changes the temperature of the flow-sensitive element. Youngs Modulus data vs. temperature is available from N.I.S.T. (or other technical references) for most all metal alloys used in the construction of prior art Coriolis flowmeters (e.g., stainless steel or Titanium). However, comparable data (e.g., elastic modulus vs. temperature) for elastic polymers are generally not available or are published at very few temperatures. Hence, prior art suggesting or describing the use of plastic for fabricating a Coriolis flowmeter, which also mention means for sensing the temperature of the flow-sensitive element (e.g., see ‘815, col. 4, lines 59-67), fail to describe how to implement effective temperature compensation over a range of operating temperatures for any given elastic polymeric material. Significantly, without such temperature compensation, the meter would not be usable in applications wherein the sensor temperature differs substantially from that at calibration.

SUMMARY OF THE PRESENT INVENTION

[0010] It is an aspect of the present invention to provide a method of fabricating a Coriolis flowmeter from an elastic polymeric material having flow sensitive element(s) integrally connected to a suitable mounting base (or manifold) of the same material free of mechanical joints or adhesives thereby providing an unyielding, fixed boundary condition for the vibrating sensitive element.

[0011] It is another aspect of the present invention to provide a method of fabricating a Coriolis flowmeter from an elastic polymeric material having a flow sensitive element integrally connected to a suitable mounting base (or manifold) of the same material free of adhesives or mechanical joints thereby avoiding differential thermal expansion/contraction that would otherwise undermine the integrity and reliability of the boundary condition at the ends of the vibrating flow sensitive element.

[0012] It is another aspect of the present invention to provide a method of fabricating a Coriolis flowmeter from an elastic polymeric material employing a flow sensitive element that does not use tubing thereby avoiding the additional processing steps such as annealing and etching thereby simplifying the flowmeter fabrication process.

[0013] It is another aspect of the present invention to provide a method of fabricating a Coriolis flowmeter from an elastic polymeric material and forming a flow sensitive element (and flow passageways therein) without using low-melting point fusible metal alloys that could permanently contaminate the flow passageway(s).

[0014] It is another aspect of the present invention to provide a method of fabricating a Coriolis flowmeter from an elastic polymeric material allowing the fabrication of a flow sensitive element with comparatively thin-walls and/or with relatively small diameter flow passageways therein.

[0015] It is yet another aspect object of the present invention to provide a method for calibrating a Coriolis flowmeter fabricated from any elastic material (metal or plastic) allowing for accurate temperature compensation of the flow sensitive element's spring constant over any useful operating temperature range of the flowmeter.

[0016] Briefly, an embodiment of the present invention includes a structure employing a flow-sensitive element comprising two substantially identical members wherein each member is shaped in the form of a rectangular "U" (or a triangle among other possible shapes that may be fabricated from straight sections) which extend from a support to which they are integrally connected. Fluid flows through each member of the flow-sensitive element in a hydraulically serial (or parallel) fashion via suitable external fluid connections. The "legs" of the flow sensitive members may have circular, oval, rectangular, hexagonal, or octagonal cross-section. The structure is fabricated from a single piece of elastic polymeric material. The fabrication process involves either CNC (computer numerical control) machining the entire structure from a single piece of polymeric material and drilling the flow passageways as a secondary operation. Alternatively, the structure can be fabricated by injection molding, the flow passageways being formed by a combination of a solid core employed within the mold and/or secondary drilling operations after the part is removed from its mold. These fabrication methods yield a completely functioning (i.e., dynamically responsive) flowmeter after secondary (post-molding) operations. External holes (from coring or drilling) are filled by a suitable secondary procedure (e.g., welding).

[0017] These and other objects and advantages of the present invention will no doubt become apparent to those skilled in the art after having read the following detailed description of the various embodiments illustrated in the figures of the drawing.

BRIEF DESCRIPTION OF THE DRAWING

[0018] Figure 1. Illustration of a partially constructed Coriolis flow sensor subassembly fabricated from an elastic polymeric material without internal flow passageways.

[0019] Figure 2. Illustration of a partially constructed Coriolis flow sensor subassembly fabricated from an elastic polymeric material with internal flow passageways formed by drilling.

[0020] Figure 3. Illustration of a partially constructed Coriolis flow sensor subassembly fabricated from an elastic polymeric material with sealed drill-holes for internal flow passageways.

[0021] Figure 4. Illustration of a partially assembled Coriolis flow sensor with excitation magnet-coil assembly and motion-sensing magnet/coil assemblies.

[0022] Figure 5. Illustration of a partially assembled Coriolis flow sensor fabricated from an elastic polymeric material connected to metering electronics.

[0023] Figure 6. Frequency vs. temperature data obtained from a Coriolis flow sensor fabricated from PFA.

[0024] Figure 7. Illustration of temperature sensing means bonded to the elastic polymeric material.

[0025] Figure 8. Illustration of additional embodiments of flow-sensitive elements.

DETAILED DESCRIPTION

[0026] The Figures (FIGS.) and the following description describe certain embodiments by way of illustration only. One skilled in the art will readily recognize from the following description that alternative embodiments of the structures and methods illustrated herein may be employed without departing from the principles described herein. Reference will now be made in detail to several embodiments, examples of which are illustrated in the accompanying figures. It is noted that wherever practicable similar or like reference numbers may be used in the figures and may indicate similar or like functionality.

[0027] Figure 1 illustrates a solid piece 110 of polymeric material, CNC-machined from a single block of elastic polymeric material, according to one embodiment. The flow-sensitive element of subassembly 110 is comprised of two square "U"-shaped assemblies 120 and 130. However, subassembly 110 is devoid of flow passageways to allow fluid to flow through the structure. Sub-assembly 110 can also be formed by injection molding but, as with the CNC-machined version, without any provision for flow passageways. By the very nature of how structure 110 is fabricated (i.e., CNC machining or injection molding), each "U" is integrally connected to "isolation plates" 175, 180 and 185, 190 (which establish boundary conditions for vibration of the "U"-shaped structures 120 and 130) and, in turn, is integrally connected to support 155. Importantly, subassembly 110 is fabricated as one solid part devoid of mechanical joints, adhesives or without using any metal support.

[0028] Figure 2 illustrates sub-assembly 210, but with flow passageways 240 and 260 drilled completely end-to-end laterally along the centerline of the "end-section" of each "U", according to one embodiment. Likewise, flow passageways 245, 250, 265 and 270 are drilled completely through along the centerline of the side-legs of each "U" and through to exit the rearmost end of support 255 (not shown). Additionally, according to one embodiment, to complete fabrication of flow channels through each "U", the drilled openings are sealed as illustrated in Figure 3 wherein each hole at the end "U" is sealed by welding or by melting plastic into the drilled entrances of passageways 340, 345, 350 and 360, 365, 370. According to one embodiment, to prevent blockage of the flow passageways during the sealing or welding operation, a mandrel with a rounded-tip is inserted along the length of each passageway prior to sealing holes allowing the plastic melt to form a smooth surface against the rounded tip of the mandrel thereby preventing internal blockage of the flow passageway.

Plumbing connections (not shown) configured at the rear of block 355 allow fluid to flow through each "U" in a hydraulically serial or parallel manner.

[0029] Members of the flow-sensitive element are not limited to the square "U"-shape shown in Figures 1 and 2, and can have other shapes that may be fabricated from straight sections. Figure 8 illustrates four example shapes for the flow-sensitive element members: triangle (options (A) and (E)), square (option (B)), trapezoid (option (C)), and straight line (option (D)).

[0030] Figure 4 depicts a subassembly 410 of a Coriolis flowmeter having a pair of sensitive elements 420 and 430 integrally attached to support block 455, according to one embodiment. Fluid material is introduced at the rear of block 455 and is directed to flow in the same direction through each flow sensitive element 420 and 430 in a hydraulically serial or parallel (i.e., split flow) manner. Flow sensitive structures 420 and 430 extend through isolation plates 475, 480, 485, 490 to support block 455. Support block 455, flow sensitive structures 420 and 430 and isolation plates 475, 480, 485, 490 are integrally connected as they are all fabricated from a single monolithic piece of elastic polymeric material.

[0031] Figure 4 discloses a magnet and coil "driver" comprised of permanent magnet 492 and coil 494 fixedly attached respectively to flow sensitive elements 420 and 430, which are caused to vibrate in phase opposition similar to the tines of a tuning fork. Figure 5 illustrates driver coil 510 is energized by signals received from meter electronics 522 over path 524. The material flow through the vibrating flow tubes generate Coriolis forces which are detected by magnet/coil inductive "pick-offs" (or "velocity sensors") located on opposite sides of flow sensitive structures 520 and 530. These sensors generate signals responsive to the motion generated in the side legs of flow sensitive structure 520 and 530 due to flow-induced Coriolis forces. The output signals of these magnet/coil inductive sensors are transmitted over paths 526 and 528 to meter electronics 522 which processes these signals and applies output information over path 529 indicative of the fluid material flow rate.

[0032] The vibration of elements 520 and 530 in phase opposition at their natural frequency is analogous to the vibrating tines of a tuning fork and can be modeled as a damped second-order system. Neglecting dampening, the resonant frequency in the excitation (or "drive") mode wherein elements 520 and 530 are oscillated in phase opposition, ω_d is expressed as:

$$\omega_d = \sqrt{(k_d/m)}, \quad (1)$$

where the natural circular frequency $\omega_d = 2\pi f_d$, f_d = natural frequency in cycles/second and $m = m_{element} + m_{fluid}$ and the spring constant k_d is proportional to the elastic modulus of the material in the "drive" or excitation mode. The terms $m_{element}$ and m_{fluid} respectively represent the effective mass of the element 520 (or 530) and the mass of the fluid contained therein. For metal alloys (e.g., 316L stainless steel) the elastic modulus and it's variation with temperature is well-documented. However, such is not the case with elastic polymers. The variation of spring constant, k, which is necessary to properly compensate for the temperature variation of the spring constant of an elastic polymeric material with vibrating sensitive elements 520 and 530, is not documented. In particular, the elastic modulus that requires compensation is that corresponding to the twist (torsion) or Coriolis mode, k_c. However, from Equation (1), it can be seen that

$$k_d = m\omega_d^2, \quad (2)$$

and in the twist (torsion) or "Coriolis" response mode,

$$k_c = m\omega_c^2, \quad (3)$$

wherein k_c is the shear modulus of the elastic polymer and can be related to k_d by the Lame' constant μ as expressed in the following equation:

$$k_c = k_d / 2\,(1 + \mu) = m\omega_d^2 / 2\,(1 + \mu). \quad (4)$$

[0033] Thus, measuring the variation of ω_d^2 with temperature allows one to measure a quantity proportional to the variation of the material's shear modulus (i.e., the material's elastic modulus in the response or Coriolis mode) over a given temperature range as illustrated in Figure 6. This consideration applies to not only elastic polymers, but any suitable elastic material including metal, ceramic, and glass materials.

[0034] With reference to Figure 7, temperature sensing means 742 is bonded to the polymeric material and communicates the temperature of the polymeric material over path 744 to meter electronics 722, according to one embodiment. Meter electronics 722 contains information proportional to ω_d^2 versus temperature thereby allowing the meter electronics to properly account for the variation of the material's elastic modulus (or equivalently, the material's shear modulus) with temperature that (in combination with other factors) is a proportional factor that relates the measured signals to the fluid mass flow rate flowing through the device.

[0035] Coriolis flowmeters exhibit a flow rate indication even though no fluid is flowing through the meter. This indication is referred to as the "zero flow offset" or "Z.F.O.". One of the contributor's to Z.F.O. is a structural and/or mass imbalance from left to right causing the "U" structures to twist relative to one another as if fluid were flowing through the device.

Figure 4 illustrates two adjustment screws 495 and 496 that allow independent manual adjustment of the sensor's moment of inertia of each flow sensitive element 420 and 430 in the sensor's response mode as required in order to minimize the magnitude of the Z.F.O. with a simple screwdriver adjustment.

[0036] A mass or structural imbalance between the two "U" structures may cause the Q-factor of the oscillating structure to be lower (i.e., the "tuning fork structure" comprised of 420 and 430 may not be balanced), thereby forcing the meter electronics to deliver more energy to maintain sufficient amplitude of oscillation in order to keep the sensor's measurement sensitivity within acceptable levels. To adjust the imbalance between the two "U" structures (420 and 430), in one embodiment threaded rods with attached weights (or "nuts") 497 and 498 are added as a simple mean of adjustment to better balance the sensor's sensitive elements (420 and 430) akin to balancing the tines of tuning fork.

What is claimed is:

1. A method for fabricating a Coriolis flowmeter from an elastic polymeric material, comprising:

fabricating a subassembly structure of the Coriolis flowmeter from the elastic polymeric material, the subassembly structure comprising two flow-sensitive members integrally connected to a base, each of the two flow-sensitive members comprising one or more straight sections;

fabricating flow passageways along the straight sections of the two flow-sensitive members; and

sealing entrances of the flow passageways.

2. The method of claim 1, wherein sealing the entrances of the flow passageways further comprises:

welding or melting elastic polymeric material into the entrances of the flow passageways.

3. The method of claim 2, wherein sealing the entrances of the flow passageways further comprises:

inserting a mandrel with a rounded-tip along a length of a flow passageway prior to sealing an entrance of the flow passageway for allowing the elastic polymeric material to form a smooth surface against the rounded tip of the mandrel thereby preventing internal blockage of the flow passageway.

4. The method of claim 1, wherein fabricating the subassembly comprises:

computer numerical control (CNC) machining the subassembly structure from a single monolithic piece of elastic polymeric material.

5. The method of claim 1, wherein fabricating the subassembly comprises:

injection molding the subassembly structure using the elastic polymeric material.

6. The method of claim 1, wherein fabricating the flow passageways along the straight sections of the two flow-sensitive members comprises:

drilling the flow passageways along the straight sections of the two flow-sensitive members.

7. A Coriolis flowmeter, comprising:

a base comprising openings configured to allow fluid to flow through the Coriolis flowmeter;

two flow-sensitive members each of which comprising one or more straight sections and flow passageways fabricated along the straight sections for the fluid to flow through, wherein the two flow-sensitive members are integrally connected to the base, and the two flow-sensitive members and the base are all fabricated from an elastic polymeric material;

two motion sensors each of which fixedly attached to one of the two flow-sensitive members and configured to generate signals responsive to relative motions generated by the two flow-sensitive members due to a Coriolis force induced by the fluid flowing through the Coriolis flowmeter; and

metering electronics communicatively connected to the two sensors and configured to receive the signals and generate output information indicative of the flow rate of the fluid that flows through the Coriolis flowmeter.

8. The Coriolis flowmeter of claim 7, wherein each of the two flow-sensitive members comprises a rectangular U-shape member, each of the rectangular U-shape members comprises a straight end-section parallel to the base and two straight side-legs integrally connecting the end section to the base.

9. The Coriolis flowmeter of claim 7, further comprising at least one isolation plate configured to establish a boundary condition for vibration of the two flow-sensitive members, wherein the two flow-sensitive members are integrally connected to the base and the at least one isolation plate, and the two flow-sensitive members, the base, and the at least one isolation plate are all fabricated from a single monolithic piece of the elastic polymeric material.

10. The Coriolis flowmeter of claim 7, wherein the two flow-sensitive members are substantially identical and in parallel to each other.

11. The Coriolis flowmeter of claim 7, wherein the two motion sensors comprise a magnet fixedly attached to one of the two flow-sensitive members and a coil fixedly attached to the other flow-sensitive member.

12. The Coriolis flowmeter of claim 7, further comprising:

a temperature sensor communicatively connected to the metering electronics and configured to measure a temperature of the two flow-sensitive members and transmit the temperature to the metering electronics, wherein the metering electronics is further configured to account for the temperature in generating the output information.

13. The Coriolis flowmeter of claim 7, wherein each of the two flow-sensitive members comprises a component configured to allow independent manual adjustment of the moment of inertia of the flow-sensitive member for minimizing a magnitude of a zero flow offset.

14. The Coriolis flowmeter of claim 13, wherein the component comprises a screw.

15. The Coriolis flowmeter of claim 7, wherein each of the two flow-sensitive members comprises a threaded rod with an attached weight to allow independent manual adjustment for balancing the two flow-sensitive members.

16. A method for calibrating a Coriolis flowmeter fabricated from an elastic material, comprising:

measuring a relative motion generated in two flow-sensitive members of the Coriolis flowmeter due to a Coriolis force induced by fluid flowing through flow passageways in the two flow-sensitive members;

measuring a temperature of the two flow-sensitive members; and

determining a calibrated flow rate of the fluid based on the elastic material, the temperature of the two flow-sensitive members, and the relative motion generated in the two flow-sensitive members.

17. The method of claim 16, wherein determining the calibrated flow rate of the fluid further comprises:

determining a factor proportional to an elastic modulus for the elastic material based on the temperature; and

determining the calibrated flow rate based on the factor and the relative motion generated in the two flow-sensitive members.

18. The method of claim 16, wherein measuring the relative motion generated in the two flow-sensitive members further comprises:

measuring a resonant frequency of the relative motion generated in the two flow-sensitive members due to the Coriolis force induced by fluid flowing through flow passageways in the two flow-sensitive members, wherein determining the calibrated flow rate of the fluid further comprises determining the calibrated flow rate of the fluid based on the elastic material, the temperature of the two flow-sensitive members, and the resonant frequency.

19. The method of claim 18, wherein determining the calibrated flow rate further comprises:

determining a factor that measures a ratio of a square of the resonant frequency versus the temperature; and

determining the calibrated flow rate based on the factor and the relative motion generated in the two flow-sensitive members.

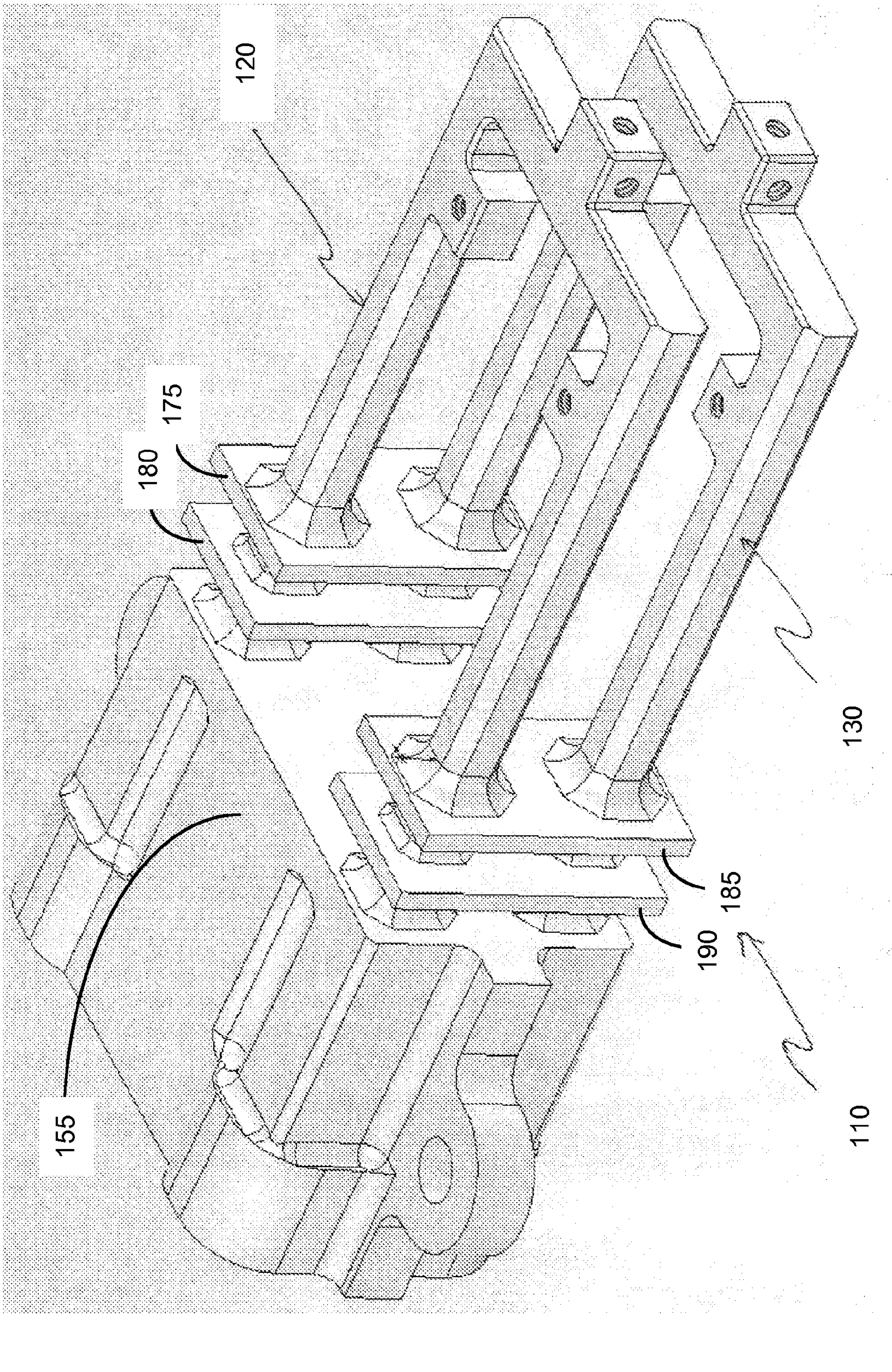

Figure 1

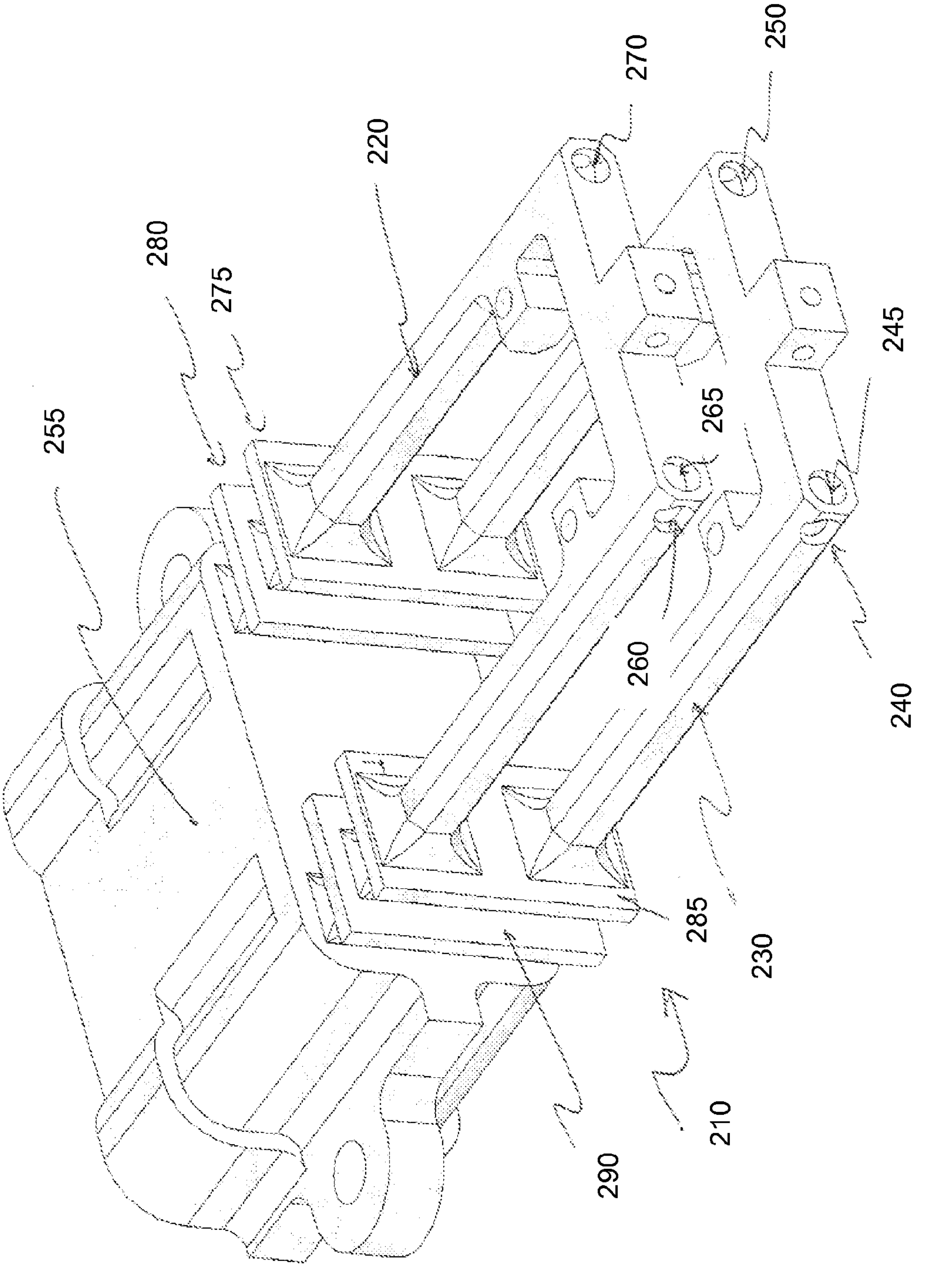

Figure 2

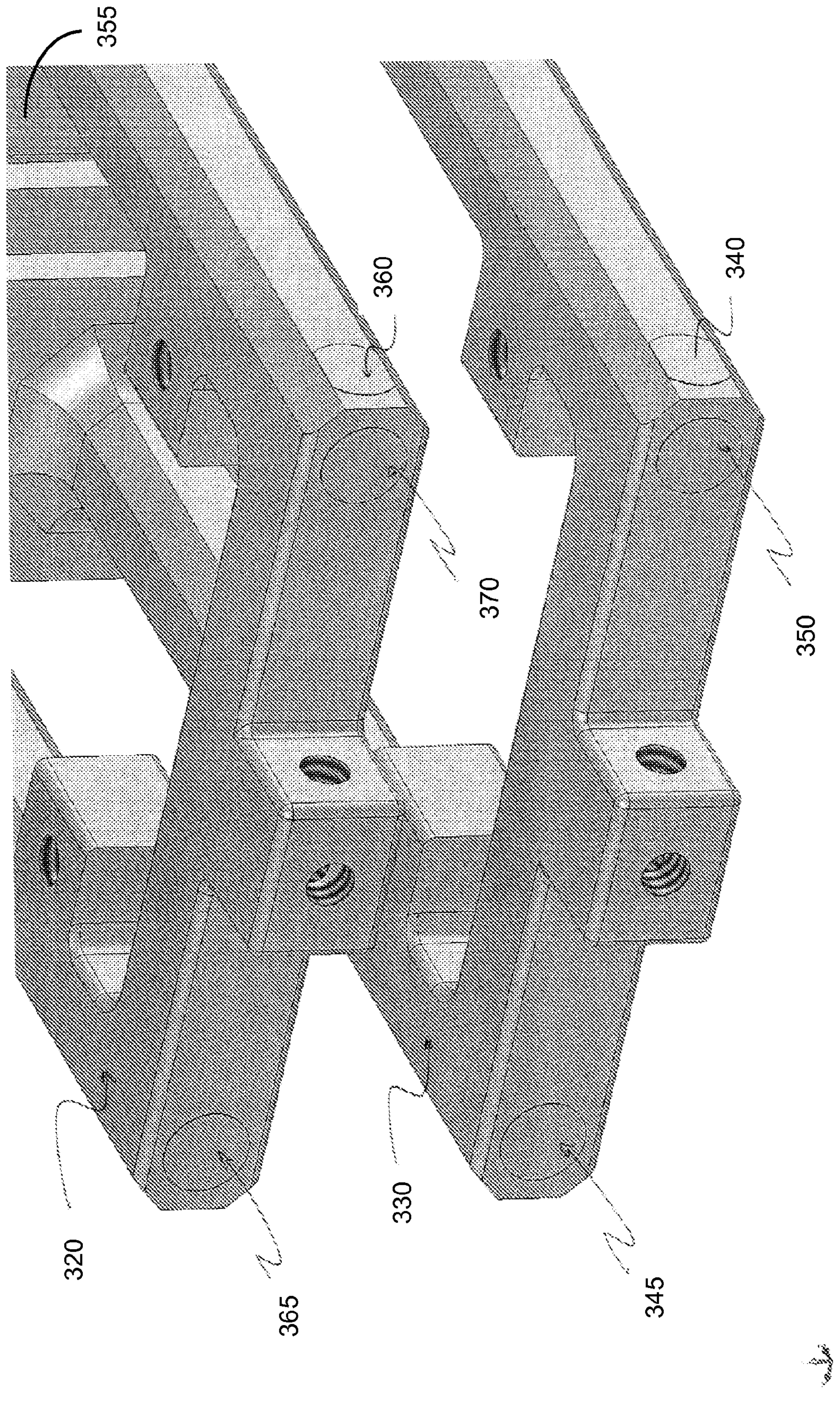

Figure 3

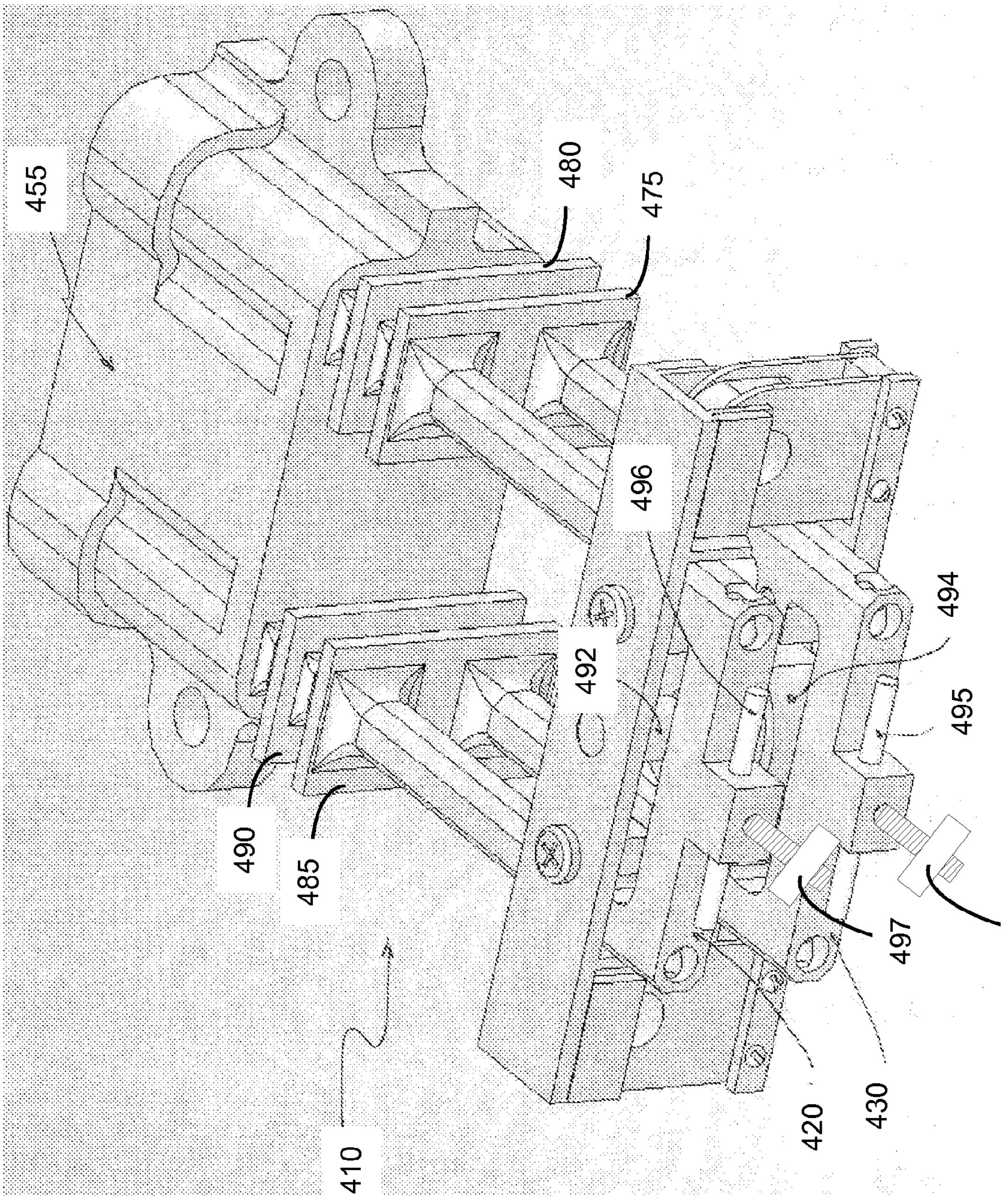

Figure 4

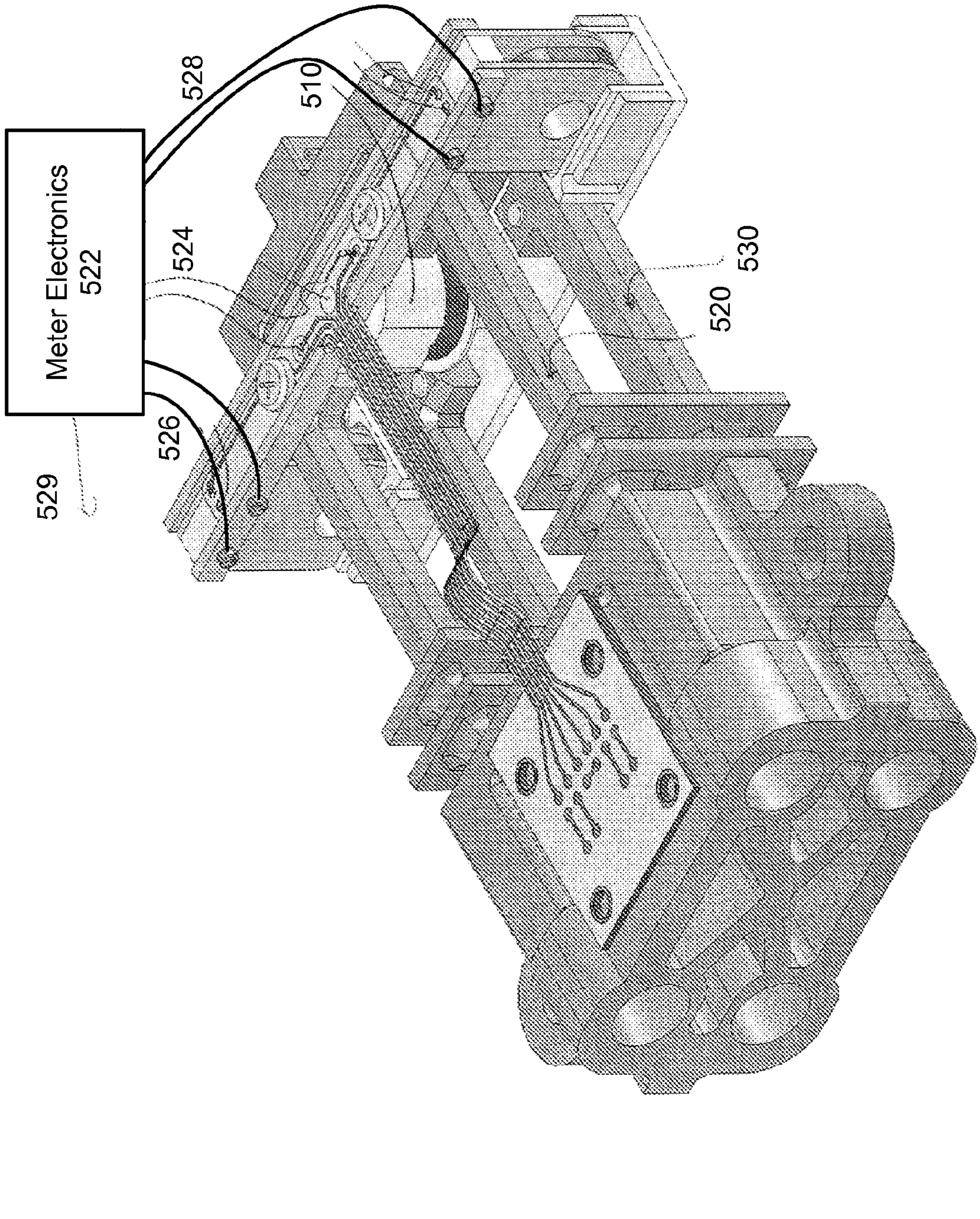

Figure 5

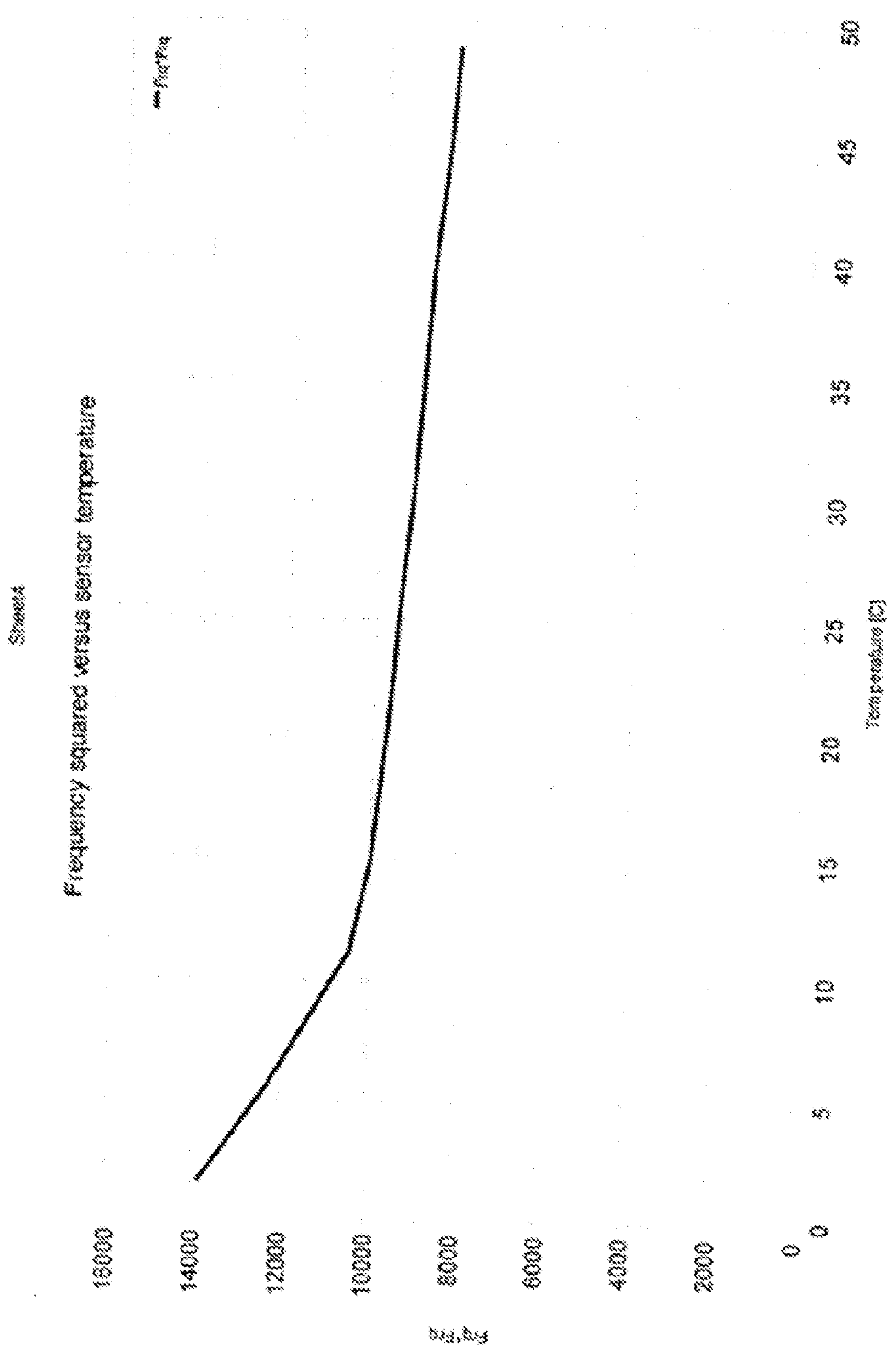
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Figure 6

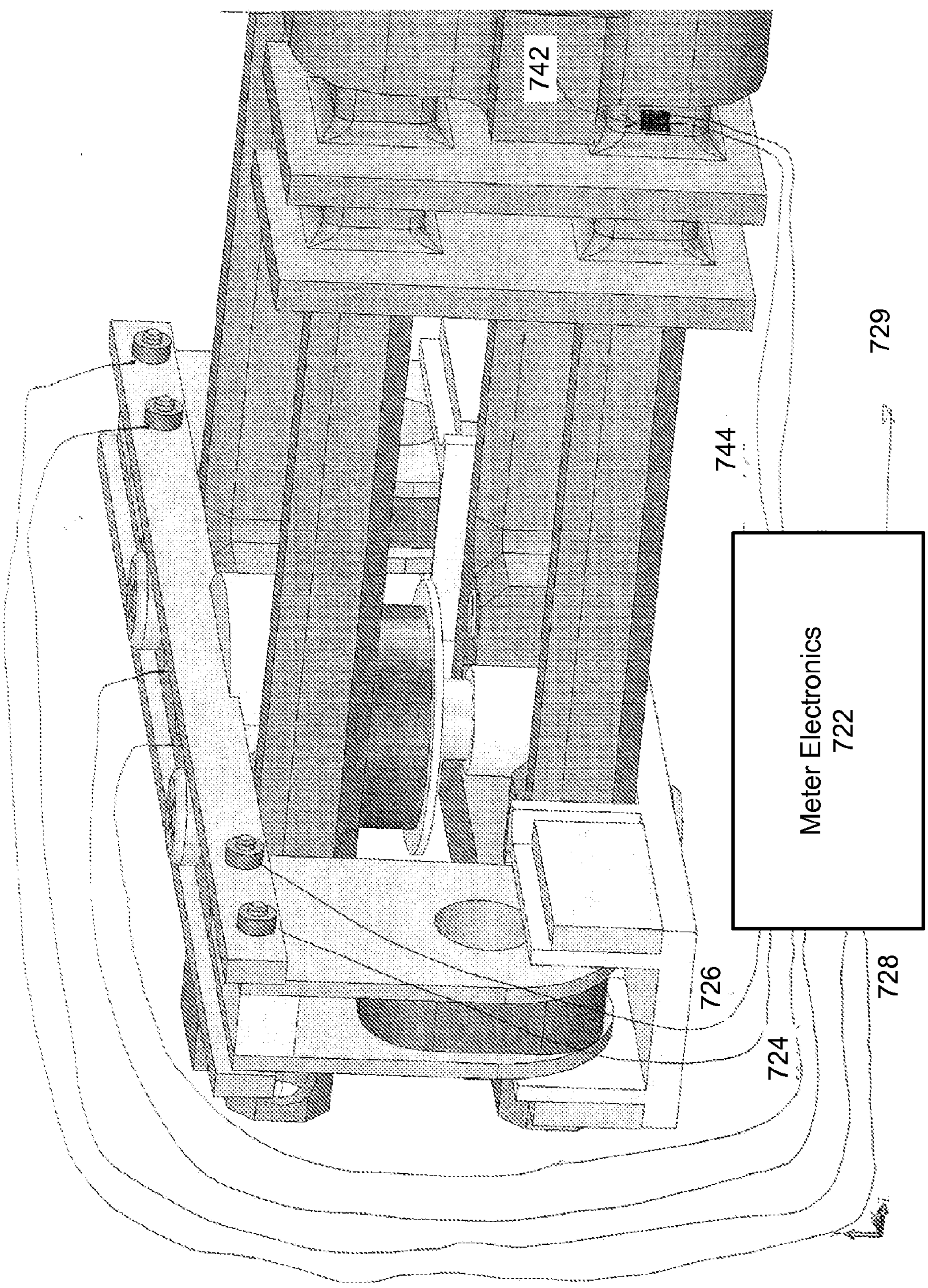

Figure 7

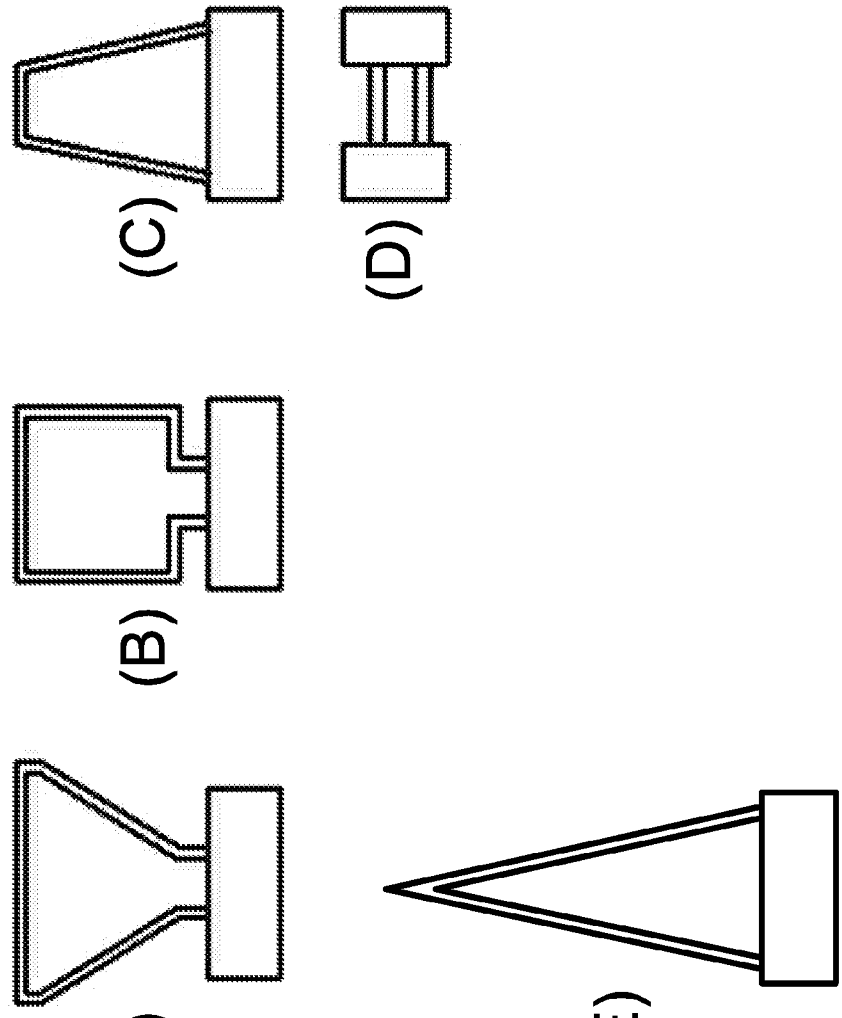

Figure 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2010/034647

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - G01F 1/84 (2010.01)
USPC - 73/861.357
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(8) - G01F 1/78, 1/84 (2010.01)
USPC - 73/861.351, 861.354, 861.355, 861.356, 861.357; 29/428

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 practicable, search terms used)
MicroPatent, Patbase, Google Patent, Google

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 6,450,042 B1 (LANHAM et al) 17 September 2002 (17.09.2002) entire document	1-6
Y	US 5,373,634 A (LIPP) 20 December 1994 (20.12.1994) entire document	1-6
Y	US 2005/0048873 A1 (ALBERTS et al) 03 March 2005 (03.03.2005) entire document	4
Y	US 4,609,138 A (HARRISON) 02 September 1986 (02.09.1986) entire document	3
A	What is the Coriolis Principle? Coriolis Principle-Oil Gas & Energy Information. 2006-2007. [retrieved on 2010-09-09]. Retrieved from the Internet: <URL: http://oil-gas-energy.blogspot.com/2006/07/coriolis-principle.html>. entire document	1-6

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"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
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
09 September 2010	17 SEP 2010

Name and mailing address of the ISA/US	Authorized officer:
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2010/034647

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

See extra sheet.

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1-6

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

Continuation of Box III.

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fees must be paid.

Group I, claims 1-6, drawn to a method for fabricating a Coriolis flowmeter from an elastic polymeric material, comprising fabricating flow passageways along the straight sections of two flow sensitive members and sealing entrances of the flow passageways.
Group II, claims 7-15, drawn to a Coriolis flowmeter comprising two motion sensors configured to generate signals responsive to relative motion induced by the fluid flow through the flowmeter; and metering electronics communicatively coupled to the two sensors configured to receive the signals and generate output information indicative of the flow rate of the fluid.
Group III, claims 16-19, drawn to method for calibrating a Coriolis flowmeter, comprising measuring a temperature of two flow sensitive members and determining a calibrated flow rate of the fluid based partly on the temperature of the two flow sensitive members.

The inventions listed as Groups I, II and III do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons: the special technical feature of the Group I invention: fabrication of flow passageways along the straight sections of two flow sensitive members and sealing entrances of the flow passageways as claimed therein is not present in the invention of Groups II and III. The special technical feature of the Group II invention: two motion sensors configured to generate signals responsive to relative motion induced by the fluid flow through the flowmeter; and metering electronics communicatively coupled to the two sensors configured to receive the signals and generate output information indicative of the flow rate of the fluid as claimed therein is not present in the invention of Groups I or III. The special technical feature of the Group III invention: a temperature sensor used in calibrating the flowmeter as claimed therein is not present in the invention of Groups I or II.

Groups I, II and III lack unity of invention because even though the inventions of these groups require the technical feature of fabricating a Coriolis flowmeter from an elastic polymeric material; the flowmeter containing sensors and metering electronics to determine a fluid flow rate, this technical feature is not a special technical feature as it does not make a contribution over the prior art in view of US 6,450,042 B1 (LANHAM et al) 17 September 2002 (17.09.2002) figures 11, 12; column 15, lines 17-64.

Since none of the special technical features of the Group I, II or III inventions are found in more than one of the inventions, unity of invention is lacking.