

AN APPARATUS FOR MEASURING MASS FLOW AND A METHOD OF FABRICATION THEREOF

[001] The invention relates to the technical field of flow sensors. More specifically, an apparatus for measuring mass flow in the form of a Coriolis flow meter, which is fabricated by means of additive manufacturing.

BACKGROUND OF THE INVENTION

[002] A mass flow meter is an instrument that calculates the flow rate of a fluid by measuring the mass of flowing fluid with respect to a unit of time. A Coriolis flow meter is a type of mass flow meter that measures parameters that include any one or a combination of mass, density, and temperature of a fluid through the Coriolis effect phenomenon.

[003] The operation of the Coriolis flow meter involves simple harmonic motion. More specifically, when fluid in the tube of the Coriolis flow meter flows at a certain speed, it does a synchronous simple harmonic motion or circular motion with the tube. This produces a reaction force of the cross product of the flow velocity of the medium and the angular velocity of the simple harmonic motion, which is the so-called "Coriolis force". Under the action of the Coriolis force, the synchronous vibration collected by sensors located at the symmetrically positioned ends of the tube to obtain a phase difference (or time difference). Since the phase difference value is proportional to the flow rate, the mass flow rate of the fluid is obtained.

[004] Conventionally, a Coriolis mass flow meter is fabricated from at least one flow tube that is mechanically bent. However, due to mechanical bending, the flow tube shall have bending stresses. In particular, due to the bending caused by stretching and extrusion steps during the fabrication process shall cause the wall thicknesses of the flow tube at its points of bending to be inconsistent. Hence, the flow tube may not have a consistent inner cross-sectional area, which may affect the zero point of the flow meter. This shall adversely affect the accuracy of the mass flow rate measurement.

[005] Furthermore, besides the flow tube, the inclusion of other components such as coil fixings, connection plates, and diverter brackets need to be brazed or welded, which is another cause of increased uncertainty in the fabrication process of the flow meter. Moreover, the installation of a Coriolis flow meter is demanding, and any mechanical stress that may act upon the Coriolis flow meter may deform its components. Hence, the zero point of the flowmeter is affected and the flow coefficient will change. This shall adversely affect the accuracy of the mass flow rate measurement.

[006] There are a few disclosed technologies over the prior art relating to an apparatus for measuring mass flow and its fabrication. Among them include the European Patent Application EP3992590A1, which discloses a method for producing a Coriolis flow meter, which involves (i) a measuring tube made of a first material is fixed to a connection area of a meter housing intended for connection to a fluid line, wherein a connection part of the connection is made of a second material is at least partially covered by a cover element made of a third material different from the first material, and (ii) the measuring tube passed through the connection part is fluid-tightly connected to the cover element in such a way that a circumferential gap remains between a measuring tube end region and the front connection part, which is free of solid material or has a vibration-damping material with solid properties.

[007] Evidently, the existing prior art exhibits the aforementioned disadvantages. Accordingly, an apparatus for measuring mass flow in the form of a Coriolis flow meter that overcomes the aforementioned disadvantages while being able to be fabricated by means of additive manufacturing is much desired.

SUMMARY OF INVENTION

[008] The present invention intends to provide an apparatus for measuring mass flow, comprising an elongate body having at least one frame portion, an arched structure that extends outwardly with respect to the frame portion, and one or more conduit portions that are part of the body and/or the arched structure. The body, the arched structure, and the conduit portions, are at least integrally formed as a single piece, whereby fluid flowing through the conduit portions has its mass flow measured when the arched structure is induced to vibrate.

[009] Preferably, the conduit portions have a tapered cross-section.

[0010] Preferably, the frame portion comprises a plurality of struts.

[0011] Preferably, the struts are arranged in an ordered manner to define one or more unit cells that constitute an ordered lattice formation.

[0012] Preferably, the arched structure comprises one or more sections, and one or more elbow portions. The elbow portions connect each section at one or more angles for at least two sections to meet at a common point.

[0013] Preferably, the arched structure further comprises one or more holder portions formed along either one of the sections or the elbow portions, with the holders including a first holder portion and a second holder portion that are each along one corresponding section, and a third holder portion that is along one of the elbow portions.

[0014] Preferably, the apparatus further comprises a first detector module that is mountable on the first holder portion, a second detector module that is mountable on the second holder portion, and an exciter module mounted on the third holder portion that induces the arched structure to vibrate.

[0015] Preferably, the conduit portions include at least one first conduit portion, at least one second conduit portion, and at least one third conduit portion, wherein the second conduit portion is between the first conduit portion and the third conduit portion.

[0016] Preferably, the first conduit portion and the third conduit portion are each formed with a branched part to divert fluid from a single flow path to one or more flow paths, or converge fluid to flow from one or more flow paths to a single flow path.

[0017] Preferably, the arched structure further comprises one or more conduit arrangements in which each conduit arrangement has a corresponding second conduit portion that is in connection with the first conduit portion and the third conduit portion.

[0018] Preferably, the arched structure further comprises one or more brace portions to provide support to its conduit arrangements.

[0019] Preferably, the apparatus further comprises an inlet and an outlet in which the body extends therebetween, and are each integrally formed with the body and/or conduit portions of the body.

[0020] Preferably, the apparatus further comprises a pair of corrugated portions that are each correspondingly attached to the inlet and the outlet, respectively.

[0021] Preferably, the apparatus further comprises a pair of flanged portions that are each correspondingly attached to each corrugated portion, respectively.

[0022] Preferably, the apparatus further comprises a housing that is mountable thereupon to cover the arched structure, and the entirety or portions of the frame portion.

[0023] Preferably, the arched structure is symmetrical along an axis that is perpendicular to a longitudinal axis of the body.

[0024] The present invention further intends to provide a method for fabricating an apparatus for measuring mass flow, comprising the steps of forming an elongate body having at least one frame portion, forming an arched structure, which extends outwardly with respect to the frame portion, and forming one or more conduit portions that are part of the body and/or the arched structure. The body, the arched structure, and the conduit portions, are at least integrally formed as a single piece, whereby fluid flowing through the conduit portions has its mass flow measured when the arched structure is induced to vibrate.

[0025] Preferably, the step of forming an elongate body having at least one frame portion further comprises the steps of forming a plurality of struts to be part of the frame portion, and forming interfaces to be part of the frame portion in which ends of the arched structure in connection therewith.

[0026] Preferably, the step of forming one or more conduit portions that are part of the body and/or the arched structure further comprises the step of forming these conduit portions to have a tapered cross-section.

[0027] Preferably, the step of forming an arched structure, which extends outwardly from the frame portion, further comprises the steps of forming one or more sections to define the arched structure, and forming one or more elbow portions to define the arched structure. The

elbow portions connect each section at one or more angles for at least two sections to meet at a common point.

[0028] One skilled in the art will readily appreciate that the invention is well adapted to carry out the objects and obtain the ends and advantages mentioned, as well as those inherent therein. The embodiments described herein are not intended as limitations on the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0029] To facilitate an understanding of the invention, there is illustrated in the accompanying drawings the preferred embodiments from an inspection of which when considered in connection with the following description, the invention, its construction and operation and many of its advantages would be readily understood and appreciated.

[0030] **FIG. 1** illustrates a side view of the apparatus of the present application according to one example embodiment.

[0031] **FIG. 2** illustrates a front view of the apparatus of the present application according to one example embodiment.

[0032] **FIG. 3** illustrates a rear view of the apparatus of the present application according to one example embodiment.

[0033] **FIG. 4** illustrates a first perspective view of the apparatus of the present application together with its ancillary components, according to one example embodiment.

[0034] **FIG. 5** illustrates a first perspective view of the apparatus of the present application together with its ancillary components that includes a housing, according to one example embodiment.

[0035] **FIG. 6** illustrates an example flowchart describing a method for fabricating the apparatus of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0036] The present invention relates to an apparatus for measuring mass flow, and a method of fabrication thereof. More specifically, the apparatus is in the form of a Coriolis flowmeter that is compatible with an additive manufacturing fabrication method. The fabricated apparatus shall have mechanical properties that ensure its stability during site installation, and high measurement accuracy when performing mass flow measurements of fluid.

[0037] From hereon, it is to be noted that, in the context of the present application, the term “fluid” may refer to matter that is in a liquid state, a gaseous state, a liquid-gaseous state, or any other state which enables the said matter to exhibit flow properties.

[0038] The invention will now be described in greater detail, by way of example, with reference to the figures. For ease of reference, common reference numerals or series of numerals will be used throughout the figures when referring to the same or similar features common to the figures.

[0039] **FIGS 1 – 5** illustrate the apparatus **100** of the present invention. More specifically, **FIG. 1** illustrates a side view of the apparatus **100**, **FIG. 2** illustrates a front view of the apparatus **100**, **FIG. 3** illustrates a rear view of the apparatus **100**, and **FIGS 4 – 5** illustrates a perspective view of the apparatus **100** together with its ancillary components.

[0040] As shown in **FIGS 1 – 5**, the apparatus **100** of the present application may be in the form of a Coriolis mass flow meter. The apparatus **100** may comprise an inlet **111**, an outlet **112**, and an elongate body **121** having at least one frame portion **122**. The apparatus **100** also further comprises an arched structure **130** that extends from the frame portion **122**, or more specifically, outwardly with respect to the frame portion **122**.

[0041] As shown in **FIGS 1 – 5**, the inlet **111** and outlet **112** may each be configured to be located at opposing ends of the elongate body **121**. In particular, the inlet **111** may receive fluid from a fluid source, and the outlet **112** may direct fluid away from the apparatus **100** after it flows through the arched structure.

[0042] As shown in **FIGS 1 – 5**, the elongate body **121** may have a length that substantially extends between the inlet **111** and the outlet **112** for them to be at substantially symmetrical locations along opposing ends of body **121**. Furthermore, the body **121** may have substantially cylindrical dimensions, but it may not be limited to as such.

[0043] As shown in **FIGS 1 – 5**, regarding the body **121**, its frame portion **122** may provide mechanical support to the arched structure **130**. For this, the frame portion **122** may be of plurality of struts **1221** that may be arranged in an ordered manner or an unordered manner. In a preferred embodiment of the apparatus **100**, the struts **1221** of the frame portion **122** are arranged in an ordered manner to define one or more unit cells that constitute an ordered lattice formation. It is to be noted that the arrangement of the struts **1221** may not be limited to as such, and they may alternatively be in the form of a honeycomb-like arrangement, a web-like arrangement, or the like.

[0044] Whilst not shown, regarding the body **121**, the struts **1221** of its frame portion **122** may substantially form an outer surface of the body **121**. Furthermore, the struts of the frame portion **122** may be in substantially connection with inner surfaces of the body **121**, the inlet **111**, the outlet **112**, or a combination thereof.

[0045] With the frame portion **122** being of a plurality of struts **1221**, the overall mass or weight of the body **121** is substantially decreased. This shall lighten the burden of the installation process of the apparatus **100** during its deployment.

[0046] As shown in **FIGS 1 – 5**, regarding the body **121**, along the its frame portion **122**, there may be one or more interface portions that include a first interface portion **1231** and a second interface portion **1232**. Both of these interface portions **1231**, **1232** are points in which the ends of arched structure **130** are in connection therewith.

[0047] As shown in **FIGS 1 – 5**, the arched structure **130** may comprise at least one conduit arrangement having one or more sections. In particular, there may be a first section **1311**, a second section **1312**, a third section **1313**, and a fourth section **1314**.

[0048] As shown in **FIGS 1 – 5**, the arched structure **130** may further comprise one or more brace portions that provide support to the conduit arrangement. In particular, there may be a first brace portion **1321** and a second brace portion **1322**. It is to be noted that the number of braces may not be limited to as such, as the number of braces depends on the capability of electrical/electronic components in performing digital signal processing, frequency tracking, coil driving, and so forth. In an alternative embodiment, the brace portions of the arched structure **130** may be omitted if so desired.

[0049] As shown in **FIGS 1 – 5**, the arched structure **130** may further comprise one or more elbow portions that adjust orientations of the sections **1311**, **1312**, **1313**, **1314**, **1315** of the conduit arrangement. In particular, there may be a first elbow portion **1321** and a second elbow portion **1322**.

[0050] As shown in **FIGS 1 – 5**, the arched structure **130** may further comprise one or more holder portions that shall allow mounting of electronic and/or electrical components thereon. In particular, there may be a first holder portion **1341**, a second holder portion **1342**, and a third holder portion **1343**.

[0051] With this, the arched structure **140** may be further described. In particular, the first section **1311** may be in connection with the first interface **1231** of the frame **121** and the first elbow portion **1331**. The second section **1312** may be in connection with the first elbow portion **1331** and the third elbow portion **1333**. The third section **1313** may be in connection with the third elbow portion **1333** and the second elbow portion **1322**. The fourth section **1314** may be in connection with the second elbow portion **1332** and the second interface **1232** of the frame **121**.

[0052] The first section **1311** may be oriented by the first interface **1231** and the first elbow portion **1331** to be at a first angle with respect to the longitudinal axis of the body **121**. The second section **1312** may be oriented by the first elbow portion **1331** and the third elbow portion **1333** to be at a second angle with respect to the longitudinal axis of the body **121**. The third section **1313** may be oriented by the third elbow portion **1333** and the second elbow portion **1322** to be at a third angle with respect to the longitudinal axis of the body **121**. The fourth section **1314** may be oriented by the second elbow portion **1332** and the second interface **1232** to be at a fourth angle with respect to the longitudinal axis of the body

121. It is to be noted that the first angle and the third angle may be supplementary angles, and that the second angle and the fourth angle may be supplementary angles. The first angle may be larger than the second angle.

[0053] With this, the second section **1312** and the third section **1313** are substantially oriented for them to meet at a common point that is distanced away from the body **121**, which is the second elbow portion **144**. This may allow the arched structure **130** to have substantial symmetry along a central axis that is perpendicular to the longitudinal axis of the body **121**. By way of example, this allows the arched structure to have a shape that may be substantially similar to a “Λ” shape.

[0054] Even as the elbow portions **1341**, **1342**, **1343** are angled, they shall be substantially shaped to provide a substantially smooth arcuate transition between each section of the conduit arrangement reduce the influence of flow field and reduce flow resistance.

[0055] Regarding the brace portions **1321**, **1322**, they may each be located adjacent to the interface of the frame **122**. More specifically, the first brace portion **1321** may be located along the first section **1311** and adjacent to the first interface **1231** of the frame **122**, while the second brace portion **1322** may be located along the fourth section **1314** and adjacent to the first interface **1231** of the frame **122**.

[0056] Regarding the holder portions **1341**, **1342**, **1343**, they may each be located adjacent to or along the any one of the elbow portions **1331**, **1332**, **1333**. More specifically, the first holder portion **1341** is located along the second section **1312** and adjacent to the first elbow portion **1331**, the second holder portion **1342** is located along the third section **1313** and adjacent to the third elbow portion **1332**, and the third holder portion **1343** is located along the second elbow portion **1343**.

[0057] **FIGS 2 – 3** illustrate a front view and a rear view of the apparatus **100**. As shown, the arched structure **140** of the apparatus **140** may include one or more conduits arrangements.

[0058] To further describe **FIGS 2 – 3**, the apparatus **100** may have a first conduit arrangement having a first section **1311a**, a second section **1312a**, a third section **1313a**, and

a fourth section **1314a**. The first conduit arrangement may have elbow portions **1331a**, **1332a**, **1333c** and holder portions **1341a**, **1342a**, **1343a** as previously described. The apparatus **100** may further have a second conduit arrangement having a first section **1311b**, a second section **1312b**, a third section **1313b**, and a fourth section **1314b**. The second conduit arrangement may have elbow portions **1331b**, **1332b**, **1333b** and holder portions **1341b**, **1342b**, **1343b** as previously described. In particular, the first conduit arrangement and the second conduit arrangement are substantially parallel with respect to each other. Furthermore, the brace portions **1231**, **1232** may each secure these conduit arrangements for their positions to be maintained as fluid flows therewithin.

[0059] By way of example, the outer diameter of the sections of each conduit arrangement may have a measurement of D . By way of a further example, the distance between a longitudinal centre axis of the section(s) of the first conduit arrangement and a longitudinal centre axis of the section(s) of the second conduit arrangement may be substantially between $1.2D$ to $1.4D$.

[0060] Whilst not shown, the apparatus **100** may be further formed with one or more conduit portions whereby fluid flows therewithin.

[0061] By way of example, there may be at least one first conduit portion that may be part of the body **121**, which internally extends between the inlet **111** and the first interface **1231** of the body **121**. The first conduit portion may be substantially formed to have a branched conduit with a branched part so as to evenly and/or equally divert fluid to flow from a single flow path to one or more flow paths.

[0062] By way of example, there may also be at least one second conduit portion that may be part of the arched structure **130**, more specifically, it may extend between the first interface **1231** and the second interface **1232** while conforming to the overall form of the conduit arrangement of the arched structure **130**. It is to be noted that, in certain embodiments, the sections **1311**, **1312**, **1313**, **1314** and the elbows **1331**, **1332**, **1333** of the conduit arrangements is the second conduit portion.

[0063] By way of example, there may also be at least one third conduit portion that may be part of the body **121**, which internally extends between second interface **1232** of the body

121 and the outlet **112**. The third conduit portion may be substantially formed to have a branched conduit with a branched part so as to converge fluid to flow from one or more flow paths to a single flow path.

[0064] It is to be noted that the first conduit, the second conduit(s), and the third conduit may be substantially in connection with each other, wherein the second conduit portion is between the first conduit portion and the second conduit portion.

[0065] It is to be noted that, in certain embodiments in which the arched structure **130** includes two or more conduit arrangements, each conduit arrangement shall have a corresponding second conduit portion. Each of these second conduit portions may be connected with a corresponding branched part of each of the first conduit portion and the third conduit portion.

[0066] Referring to **FIG. 1**, it is to be noted that the first conduit, the second conduit(s), and the third conduit may have an inner cross-section that is substantially tapered (as indicated by the section lines A-A'). By way of a first example, there inner cross-section of these conduits may include one or more substantially rounded portions and one or more substantially pointed portions in which the perimeter of the inner cross-section tapers thereto. By way of a second example, the inner cross-section of these conduits may include one or more substantially rounded portions that include a first rounded portion, and a second rounded portion that has an arc length that is smaller than the first rounded portion, in which the perimeter of the inner cross-section tapers thereto. Such a cross-section may be, by a more specific example, in the form of a teardrop shape, a convex shape, or the like.

[0067] It is to be noted the body **121**, and the arched structure **130** together with its associated components, and the conduit portions, may be integrally formed as a single piece by means of additive manufacturing. Furthermore, the inlet **111**, the outlet **112** may also be integrally formed therewith them. The techniques involved preferably relates to three-dimensional (3D) printing technologies, which may be, but shall not be limited to, powder bed fusion-based 3D printing, selective laser melting (SLM)-based 3D printing, stereolithography (SLA)-based 3D printing, digital light processing (DLP)-based 3D printing, fused deposited modelling (FDA)-based 3D printing, or the like.

[0068] **FIG. 5** further illustrates the apparatus **100** together with its ancillary items. It is to be noted that the inlet **111**, the outlet **112**, the body **121**, and the arched structure **130** may or may not be integrally fabricated with any one or a combination of these ancillary items. In particular, these ancillary items may comprise a set of electrical and/or electronic modules that include a first detector module **141**, a second detector module **142**, and an exciter module **143**; a pair of corrugated portions that include a first corrugated portion **151** and a second corrugated portion **152**; a pair of flanged portions that include a first flanged portion and a second flanged portion **161**, **162**, and a housing **170**.

[0069] Regarding the set of electrical and/or electronic modules that, the first detector module **141** may be mounted on the first holder **141**, the second detector module **142** may be mounted on the second holder **142**, and the exciter module **143** may be mounted on the third holder **143**.

[0070] In particular, for the exciter module **143**, its magnetic steel may be installed at one side of the third holder **143**, and its coil may be installed on one other side of the third holder **143**. In addition to exciter module **143** being located at a centre of the third holder **143**, it shall not obstruct the conduit arrangement of the arched structure **130** to vibrate at its natural frequency.

[0071] Regarding the corrugated portions **151**, **152**, the first corrugated portion **151** may be attached to the inlet **111**, and the second corrugated portion **152** may be attached to the outlet **112**. In particular, fluid may flow through these corrugated portions **151**, **152**.

[0072] Regarding the flanged portions **161**, **162**, the first flanged portion **161** may be attached to the first corrugated portion **151**, and the second flanged portion **162** may be attached to the second corrugated portion **151**. These flanged portions **161**, **162** substantially enable the apparatus **100** to be secured to other fluid-carrying means (e.g. pipes, conduits, etc.) that substantially provide fluid to the apparatus **100** or substantially deliver fluid away from the apparatus **100**.

[0073] Regarding the housing **170**, it may be a piece that is mountable onto the apparatus **100** in a permanent or non-permanent manner. In particular, the housing **170** may be

substantially formed with a cavity to cover the entirety of the arched structure **130** together with its associated components and its mounted electrical and/or electronic modules. Furthermore, the housing **170** may further substantially cover the entirety of the frame **122** or portions thereof. To this end, the housing **170** may be sized so as to conform to the shape of either one or both the arched structure **130** and the frame **122** of the body **121**, for them to be fitted within the cavity of the housing **170**.

[0074] Regarding the flanged portions **161**, **162**, the first flanged portion **161** may be connected to the first corrugated portion **151**, and the second flanged portion **162** may be connected to the second corrugated portion **151**. These flanged portions **161**, **162** substantially enable the apparatus **100** to be secured to other fluid-carrying means (e.g. pipes, conduits, etc.) that substantially provide fluid to the apparatus **100** or substantially deliver fluid away from the apparatus **100**.

[0075] **FIG. 6** illustrates an example flowchart describing a method for fabricating the apparatus **100** of the present invention. It is noted that the steps described in this flowchart are not to be interpreted as non-limiting, and minor modifications to the steps (e.g. additions, omissions, or swaps) are permissible by a skilled person without substantial deviation from as described. It is also to be noted that while components or modules of the apparatus **100** may not be explicitly referred, they are to be implicitly understood to be part of the apparatus **100** as previously described.

[0076] It is to be noted that the apparatus **100** may be fabricated by a three-dimensional printing device that may perform powder bed fusion-based 3D printing whereby powder material is sintered and layers of this material are printed for the apparatus **100** to be formed. Alternatively, the apparatus **100** may be fabricated via selective laser melting (SLM)-based 3D printing, stereolithography (SLA)-based 3D printing, digital light processing (DLP)-based 3D printing, fused deposited modelling (FDA)-based 3D printing, or the like.

[0077] The said printing device may further include one or more image sensors, and a machine learning module that is operated by its processor for performing any one or a combination of (i) automated monitoring of the fabrication of the apparatus **100** based on images or video of the apparatus captured by the image sensors, (ii) automatic detection of powder quality of each printed layer based on images or video of the apparatus captured by

the image sensors, and (iii) automatic detection of structural failure during printing of the apparatus **100** based on images or video of the apparatus captured by the image sensors.

[0078] It is also to be noted that the apparatus **100** may be fabricated from material such as metals via 3D printing. More specifically, it is noted that any one or a combination of the inlet **111**, outlet **112**, the body **121**, and the arched structure **130** may be generally made from stainless steel, Hastelloy, or any other type of metallic material suitable for use in 3D printing.

[0079] The example flowchart in **FIG. 6** may begin with Step **201**. Step **201** involves creating a digital model of the apparatus **100**. Preferably, this digital model may be in the form of a boundary representation that is constructed or designed by use of computer-aided design (CAD) software.

[0080] Following Step **201** is Step **202**. Step **202** involves simulating the digital model of the apparatus **100** for validating its behaviour and operations under a flow of fluid.

[0081] Following Step **202** is Step **203**. Step **203** involves converting the digital model into a mesh file. Preferably, the mesh file may be a data file in a format that is readable by printing devices, and it may be, by way of example, in .stl format.

[0082] Following Step **203** is Step **204**. Step **204** involves creating a set of printing instructions based on the mesh file by importing the mesh file into a slicer software. In particular, this set of printing instructions relates to the printing of the apparatus **100**.

[0083] Following Step **204** is Step **205**. Step **205** involves running the printing program on a printing device, which is preferably capable of performing powder bed fusion-based 3D printing.

[0084] Following Step **205** is Step **206**. Step **206** involves printing the apparatus **100**, more specifically, printing any one or a combination of the inlet **111**, the outlet **112**, the body **121** and its frame portion **122**, and the arched structure **130** together with its associated components. In particular, this step may be performed based on the set of printing instructions as created in step **204**.

[0085] With this, Step **206** may be regarded as having one or more sub-steps. It is noted that the sub-steps described are not to be interpreted as non-limiting, and minor modifications to

the steps (e.g. additions, omissions, or swaps) are permissible by a skilled person without substantial deviation from as described. Furthermore, it is to be noted that these sub-steps may be performed in a sequential manner, or in a near concurrent manner.

[0086] Step **206** may include a first sub-step that involves printing the inlet **111**, which may further include forming, by printing, portions of the first conduit. Next, there may be a second sub-step that involves forming, by printing, the body **121** together with its frame portion **121**, which may further include forming the remaining portions of the first conduit. Next, there may be a third sub-step that involves forming, by printing, the arched structure **130** together with its associated components, which may further include forming the second conduit. Next, there may be a fourth sub-step that involves forming, by printing, a remaining portion of the body **121** together with and the frame **122** for the frame **122** to be in connection with the arched structure **130**. Next, there may be a sixth sub-step that involves forming, by printing, a remaining portion of the body **121** together with the frame **122** which may further include forming a portion of the third conduit. Finally, there may include a seventh sub-step that involves forming, by printing, the outlet **111**, which may further include forming remaining portions of the third conduit.

[0087] It is to be noted that step **206** may further include a sub-step that involves printing of one or more support structures. This ensures that any one or a combination of the inlet **111**, the outlet **112**, the body **121** and its frame portion **122**, are supported as they are printed by a printing device.

[0088] It is to be noted that step **206** may further include a sub-step that involves monitoring printing of any one or a combination of the inlet **111**, the outlet **112**, the body **121** and its frame portion **122**, and the arched structure **130** together with its associated components. In particular, the image sensors of the printing device may capture one or more instances (i.e. images or live video), whereby a layer is being printed. These instances may then be provided to the machine learning module, which is operated by the processor, for it to detect printing defects.

[0089] At the end of Step **206**, it is to be noted that there shall be a printed apparatus **100** that may have the inlet **111**, the outlet **112**, the body **12**, the arched structure **130** and its

associated components, and the conduit portions, with them being integrally formed as a single piece.

[0090] Following Step **206** is Step **207**. Step **207** involves post-processing the printed apparatus **100**. In particular, the post-processing may include performing heat treatment on the printed apparatus **100** and performing removal of the support structures (if present).

[0091] Following Step **207** is Step **208**. Step **208** involves smoothing the external surfaces of the apparatus **100** by use of an abrasive blasting device. The smoothing device, may be, by way of example, a sandblasting device, or the like.

[0092] Following Step **208** is Step **209**. Step **209** involves installing the detector modules **141**, **142** and the exciter module **143** on the arched structure **130** of the apparatus **100**.

[0093] Following Step **209** is Step **210**. Step **210** involves wiring the apparatus **100** for its electrical and/or electronic connections.

[0094] Following Step **210** is Step **211**. Step **211** involves mounting the housing **170** and flanges **161**, **162** on the apparatus **100**. The housing **170** may be attached to the body **121** in a permanent or non-permanent manner. The first flange **161** may be attached to the inlet **111** in a permanent or non-permanent manner, while the second flange **162** may be attached to the outlet **112** in a permanent or non-permanent manner. Attachment in a permanent may be done by means of welding.

[0095] Finally, following Step **211** is Step **212**. Step **212** involves installing the transmitters on the apparatus **100**. With that, the apparatus **100** is ready for on-site installation and deployment.

[0096] It is to be noted that in some embodiments of the method for fabricating the apparatus **100**, Step **208** may be performed after Step **211** and prior to Step **212**.

[0097] Advantageously, the present invention adopts an arched structure **130** comprising one or more elbow portions that are angled at one or more angles and a second conduit portion having a tapered cross-section. Such an arched structure **130** may reduce fabrication difficulties when 3D printing technology is used. More specifically, the arched structure **130**

may be printed without the use of small support structures, thereby improving the consistency of the fabricated conduits of the arched structure **130** as the printed product shall have minimal to no weight variation, thereby improving its stability during operation. This enable the apparatus **100** to be fabricated in a repeatable and simple manner.

[0098] Advantageously as well, the present invention may be flexibly configured to adopt a single-distance mode or a double-distance mode. The brace portions **1321**, **1322** are optimally positioned to be located along a corresponding section of the arched structure **130** while being substantially perpendicular with respect to its corresponding section. As such, the resonant frequency and stability of the conduit portion of the arched structure **130** is high and thereby resistant to seismic effects.

[0099] Advantageously as well, the positional locations of the detectors **141**, **142** enable them to operate in an optimal manner as they are located along a corresponding section and adjacent to a corresponding elbow portion. More specifically, these locations shall enable the detectors **141**, **142** to obtain a maximum amplitude from a resonant vibration and a robust signal-to-noise ratio. Together with the exciter **143**, the apparatus **100** may operate in a closed-loop manner with a self-adjustment ability for it to be stable throughout its operation and resilient to the influence of external disturbances.

[00100] Advantageously as well, the frame portion **122** of the body **121**, and the corrugated portions **151**, **152**, may reduce the impact of deformation and stress on the apparatus **100** caused by its installation during its deployment. This shall increase the zero-point stability of the apparatus **100** to ensure repeatability in its measurements.

[00101] The operation of the apparatus **100** shall now be briefly described. During operation, fluid may flow from a fluid source and may be received by the first flanged portion **161** and the first corrugated portion **151** to reach the inlet **111**. At a conduit portion of the inlet **111**, fluid may then be diverted to flow along two flow paths wherein the fluid may equally flow into each conduit arrangement of the arched structure **130**. Then, the fluid may exit each conduit arrangement of the arched structure **130** and reach the outlet **112**. At a conduit portion of the outlet **112**, fluid may then be converged to flow along a single flow path. Then,

the fluid may flow from the outlet **112** to the second corrugated portion **152**, and subsequently, the first flanged portion **162**, to flow away from the apparatus **100**.

[00102] As fluid flows through the conduit arrangement of the arched structure **130**, the exciter module **143** may excite the arched structure **130** for its conduit arrangements to vibrate at their natural frequency. The detector modules **141**, **142** may detect a vibration waveform of the conduit arrangement with fluid flowing therethrough. A processor that may be connected to both of the detector modules **141**, **142** may then compare these vibration waveforms to determine their phase difference. By determining the phase difference between the signals, the mass flow rate of the fluid may then be determined.

[00103] With this, an apparatus for measuring mass flow and a method of fabrication thereof, has been presented and described. The present disclosure includes as contained in the appended claims, as well as that of the foregoing description. Although this invention has been described in its preferred form with a degree of particularity, it is understood that the present disclosure of the preferred form has been made only by way of example and that numerous changes in the details of construction and the combination and arrangements of parts may be resorted to without departing from the scope of the invention.

CLAIMS

1. An apparatus for measuring mass flow, comprising
an elongate body having at least one frame portion;
an arched structure, which extends outwardly with respect to the frame portion; and
one or more conduit portions that are part of the body and/or the arched structure;
wherein the body, the arched structure, and the conduit portions, are at least integrally
formed as a single piece, whereby fluid flowing through the conduit portions has its mass
flow measured when the arched structure is induced to vibrate.
2. The apparatus according to claim 1, wherein the conduit portions have a tapered
cross-section.
3. The apparatus according to claim 1 or 2, wherein the frame portion comprises a
plurality of struts.
4. The apparatus according to claim 3, wherein the struts are arranged in an ordered
manner to define one or more unit cells that constitute an ordered lattice formation.
5. The apparatus according to any one of the preceding claims, wherein the arched
structure comprises
one or more sections; and
one or more elbow portions;
wherein the elbow portions connect each section at one or more angles for at least
two sections to meet at a common point.
6. The apparatus according to claim 5, wherein the arched structure further comprises
one or more holder portions formed along either one of the sections or the elbow portions,
with the holders including
a first holder portion and a second holder portion that are each along one
corresponding section; and
a third holder portion that is along one of the elbow portions.

7. The apparatus according to claim 6, further comprising
a first detector module that is mountable on the first holder portion;
a second detector module that is mountable on the second holder portion; and
an exciter module mounted on third holder portion that induces the arched structure to vibrate.
8. The apparatus according to any one of the preceding claims, wherein the conduit portions include
at least one first conduit portion;
at least one second conduit portion; and
at least one third conduit portion;
wherein the second conduit portion is between the first conduit portion and the second conduit portion.
9. The apparatus according to claim 8, wherein the first conduit portion and the third conduit portion are each formed with a branched part to
divert fluid from a single flow path to one or more flow paths; or
converge fluid to flow from one or more flow paths to a single flow path.
10. The apparatus according any one of claims 8 or 9, wherein the arched structures further comprise one or more conduit arrangements in which each conduit arrangement has a corresponding second conduit portion that is in connection with the first conduit portion and the third conduit portion.
11. The apparatus according to claim 10, wherein the arched structure further comprises one or more brace portions to provide support to its conduit arrangements.
12. The apparatus according to any one of the preceding claims, further comprising an inlet and an outlet in which the body extends therebetween, and are each integrally formed with the body and/or conduit portions of the body.
13. The apparatus according to claim 12, further comprising a pair of corrugated portions that are each correspondingly attached to the inlet and the outlet, respectively.

14. The apparatus according to claim 13, further comprising a pair of flanged portions that are each correspondingly attached to each corrugated portion, respectively.
15. The apparatus according to any one of the preceding claims, further comprising a housing that is mountable thereupon to cover the arched structure, and the entirety or portions of the frame portion.
16. The apparatus according to any one of the preceding claims, wherein the arched structure is symmetrical along an axis that is perpendicular to a longitudinal axis of the body.
17. A method for fabricating an apparatus for measuring mass flow according to claim 1, comprising the steps of
 - forming an elongate body having at least one frame portion;
 - forming an arched structure, which extends outwardly with respect to the frame portion; and
 - forming one or more conduit portions that are part of the body and/or the arched structure;wherein the body, the arched structure, and the conduit portions, are at least integrally formed as a single piece, whereby fluid flowing through the conduit portions has its mass flow measured when the arched structure is induced to vibrate.
18. The method according to claim 17, wherein the step of forming an elongate body having at least one frame portion further comprises the steps of
 - forming a plurality of struts to be part of the frame portion; and
 - forming interfaces to be part of the frame portion in which ends of the arched structure in connection therewith.
19. The method according to any one of claims 17 or 18, wherein the step of forming one or more conduit portions that are part of the body and/or the arched structure further comprises the step of forming these conduit portions to have a tapered cross-section.

20. The method according to any one of claims 17 to 19, wherein the step of forming an arched structure, which extends outwardly from the frame portion, further comprises the steps of

forming one or more sections to define the arched structure; and

forming one or more elbow portions to define the arched structure;

wherein the elbow portions connect each section at one or more angles for at least two sections to meet at a common point.