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(54) Title of the Invention: Ultrasonic liquid flow meter

Abstract Title: Ultrasonic flowmeter with reflectors comprising an outer surface element of the meter body

(57) An ultrasonic liquid flow meter comprises a meter body 4 comprising a through channel 5 for liquid flow, a pair of ultrasonic transducers 8a, 8b, attached to the meter body and comprising a first transducer configured to emit ultrasound through the meter body into the through channel and a second transducer configured to receive ultrasound, and one or more reflectors 12a, 12b, 12c, configured to direct ultrasound emitted by the first transducer to the second transducer, wherein each of the one or more reflectors comprises an outer surface element of the meter body. The reflectors may comprise an air backing or a backing layer attached to the outer surface element. A method of manufacturing the meter body is disclosed comprising injection moulding the meter body.

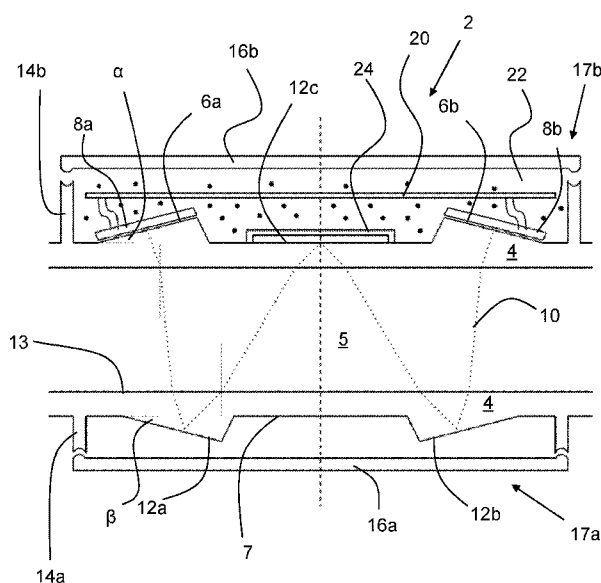


FIG. 7

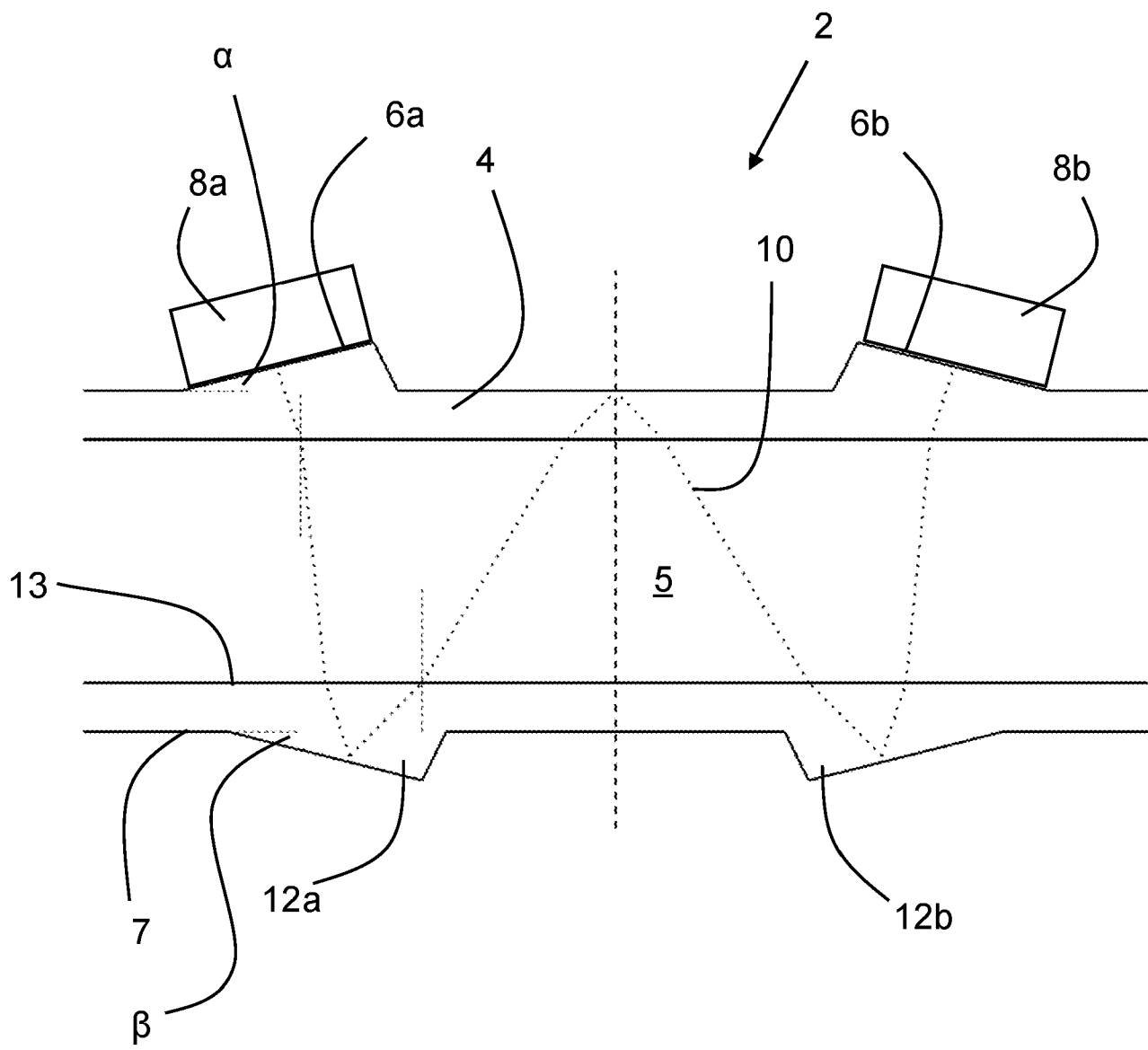
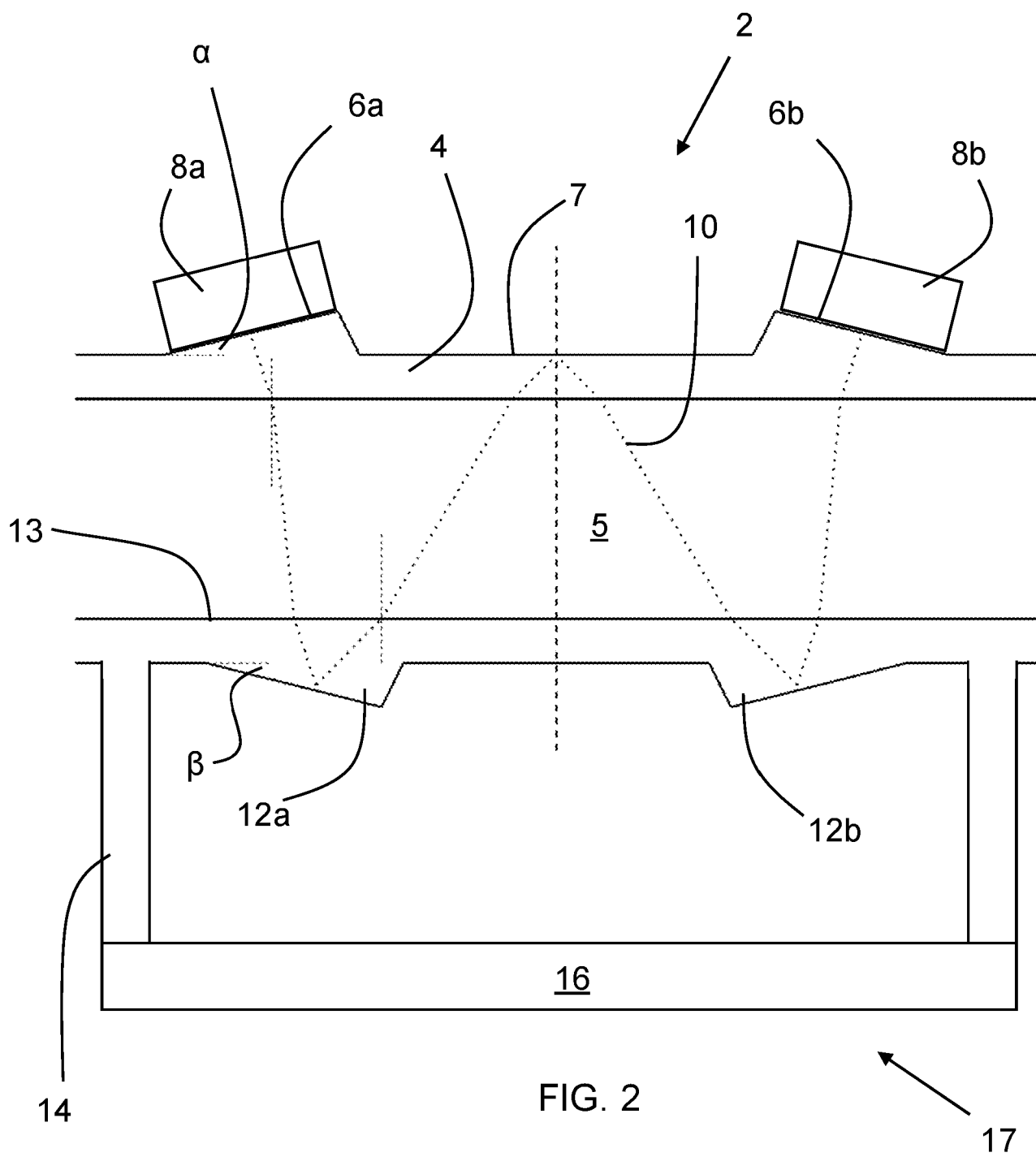


FIG. 1



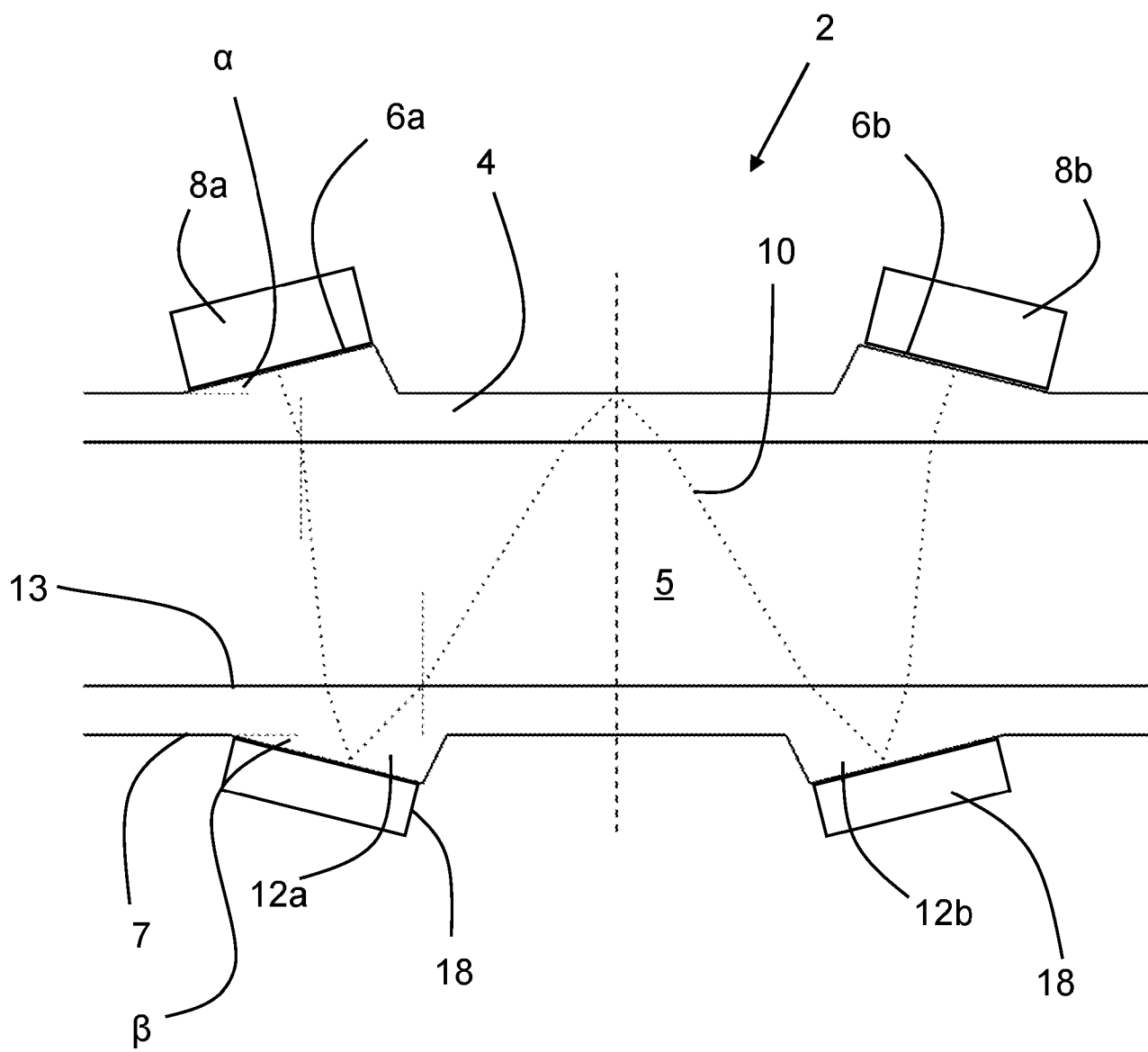


FIG. 3

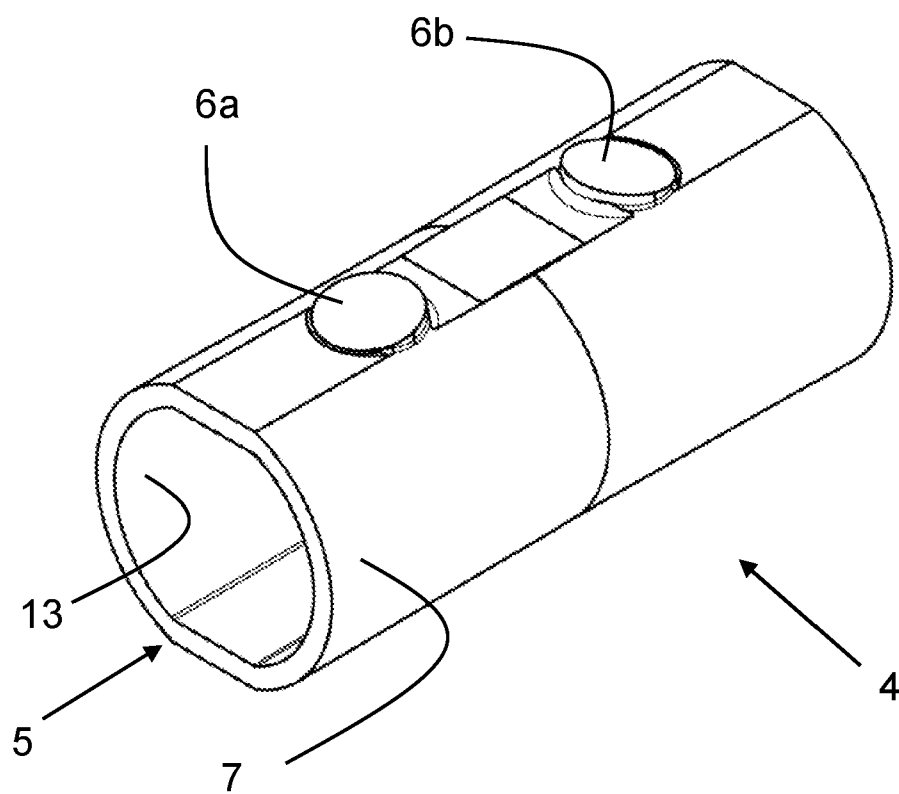


FIG. 4A

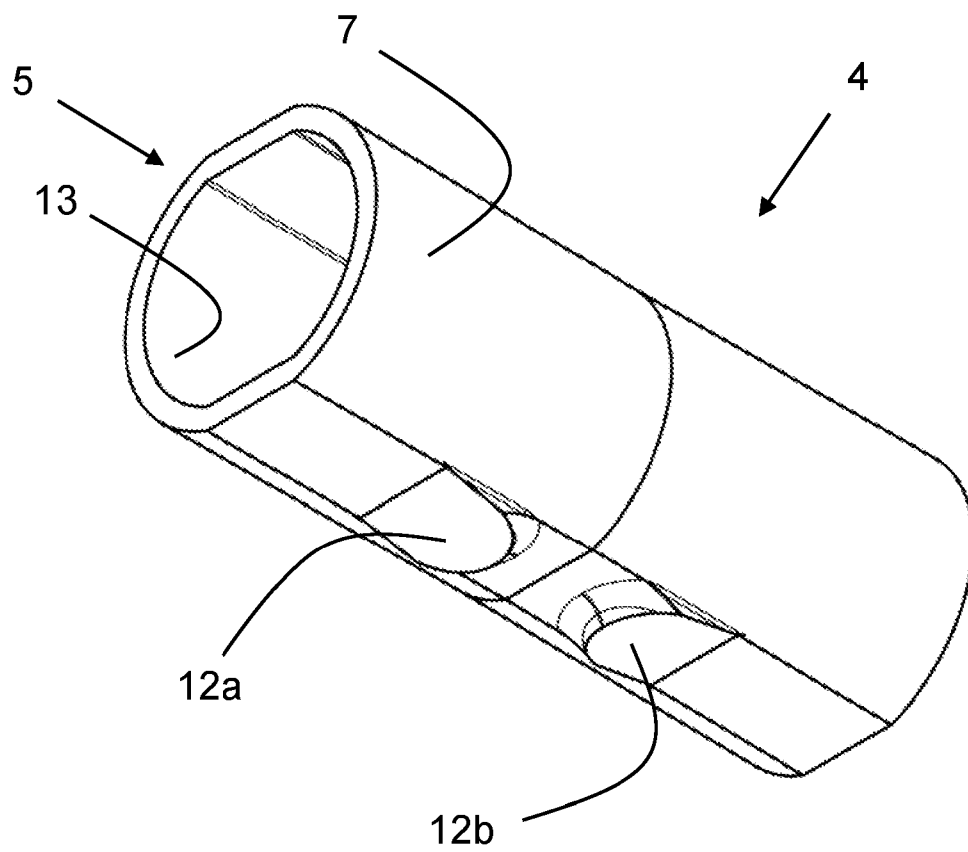


FIG. 4B

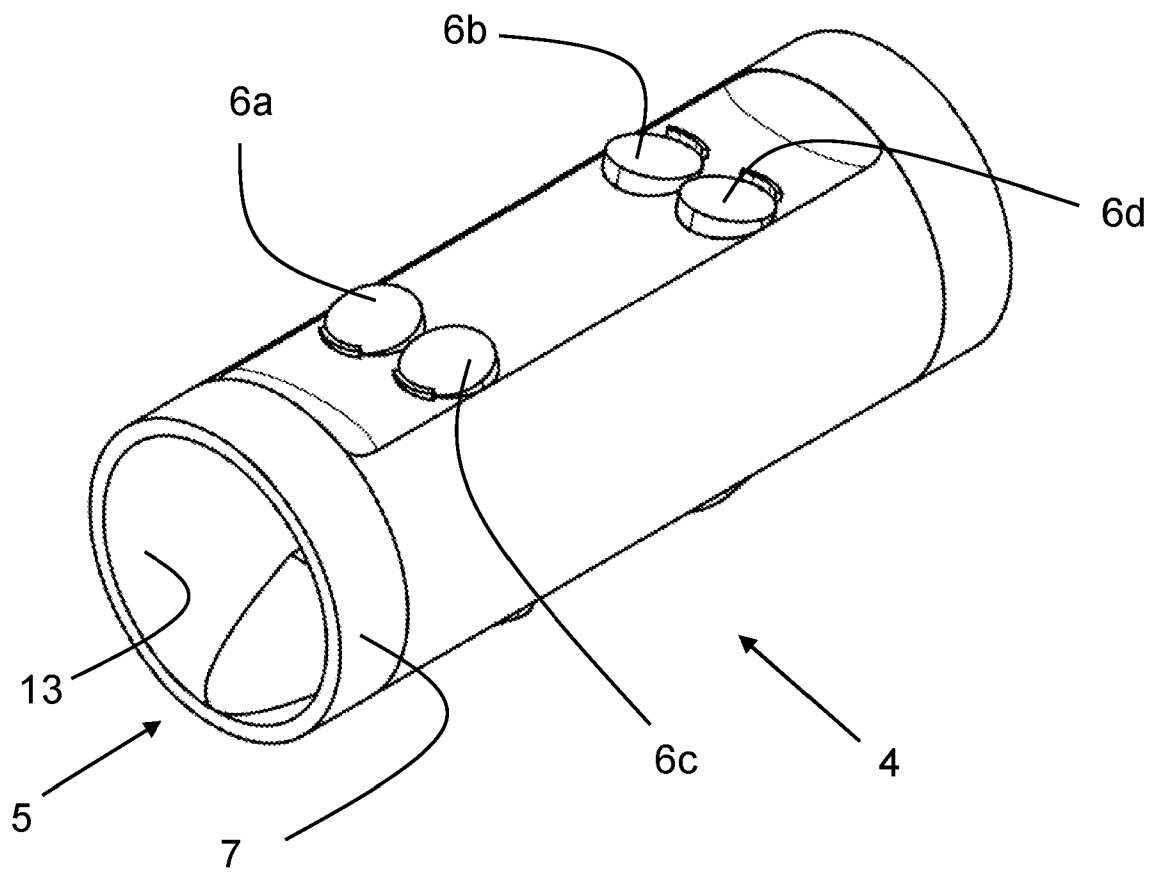


FIG. 5A

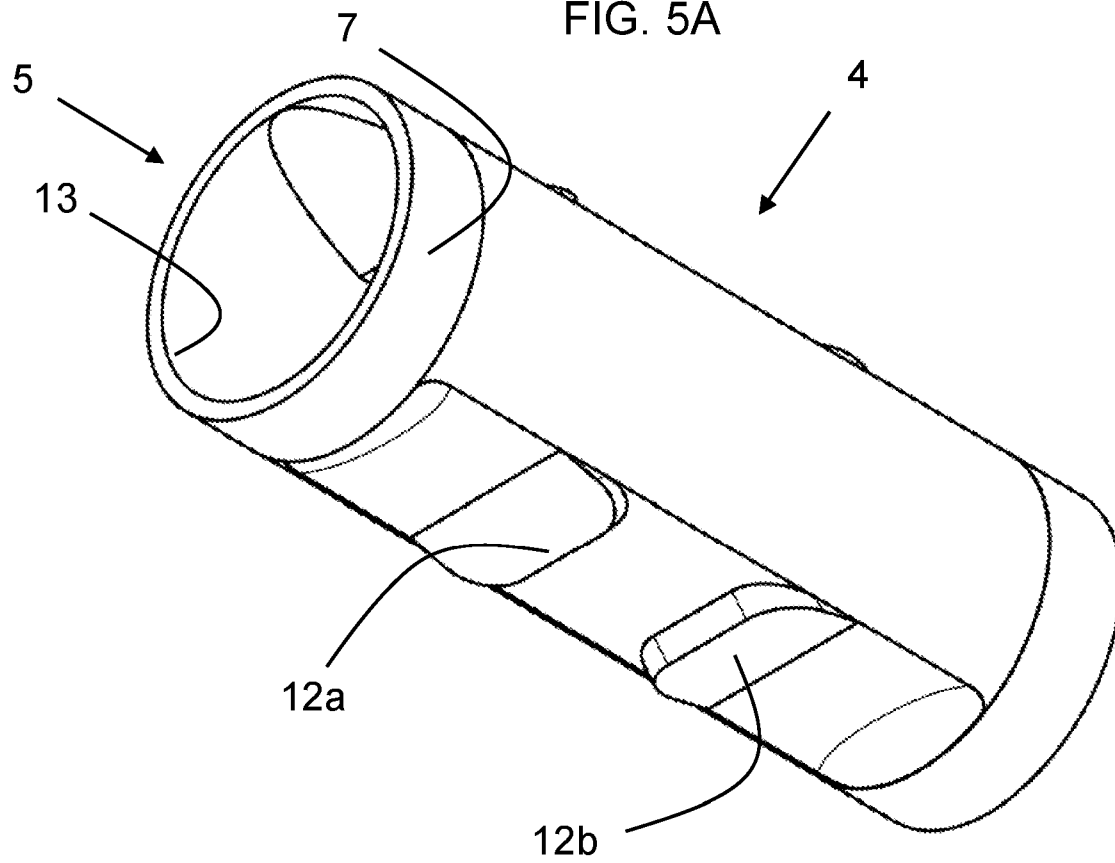


FIG. 5B

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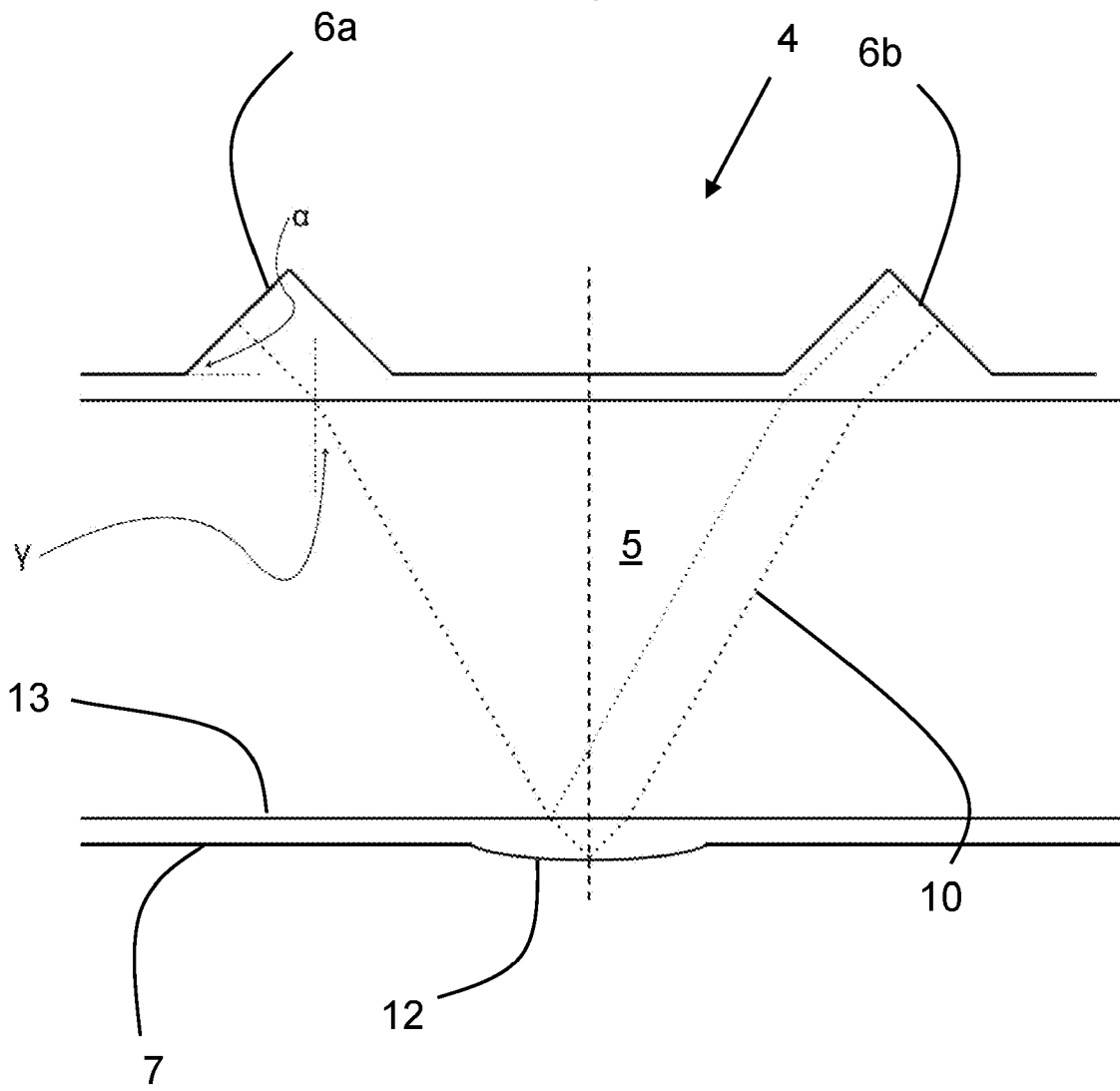


FIG. 6

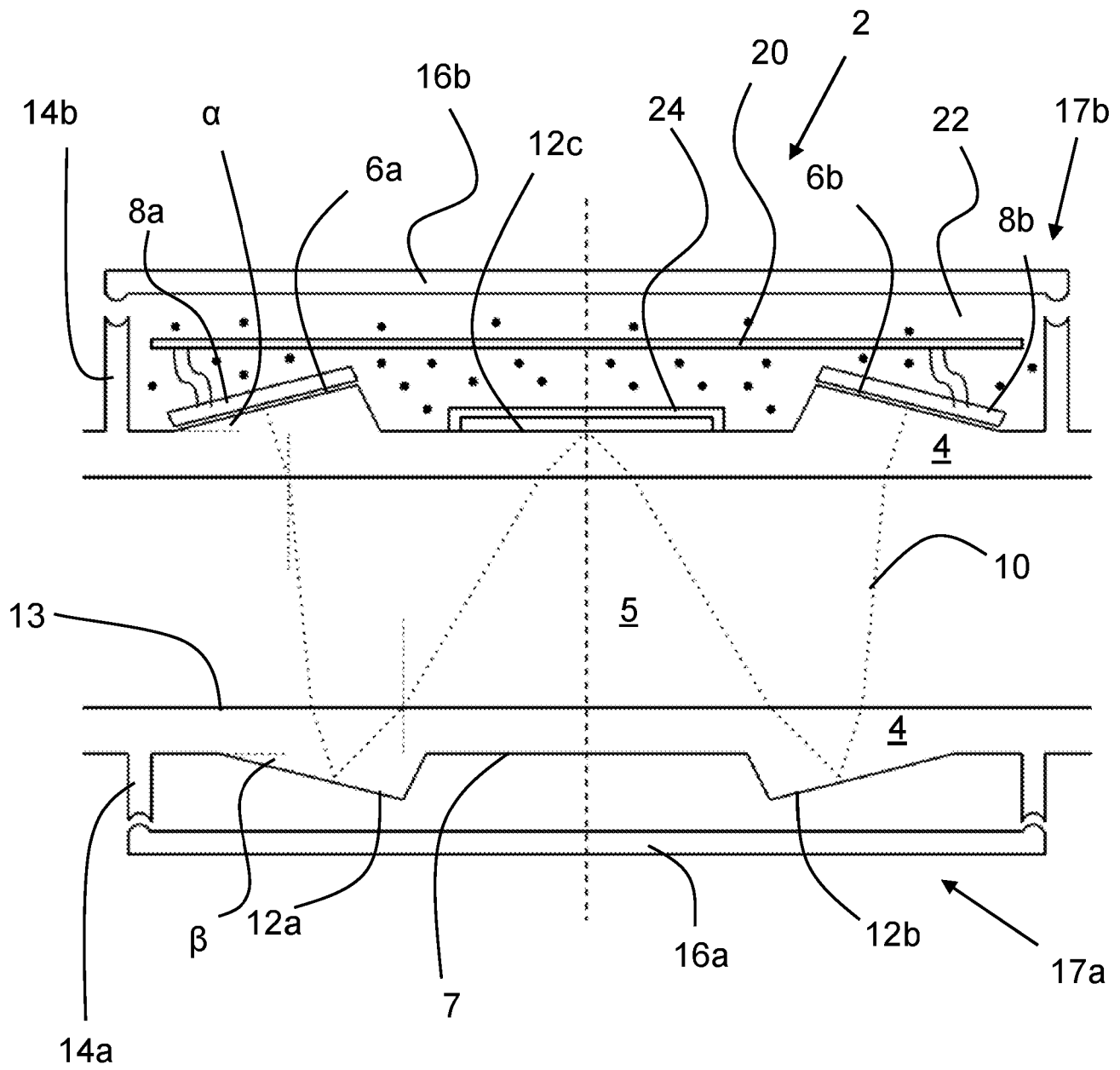


FIG. 7

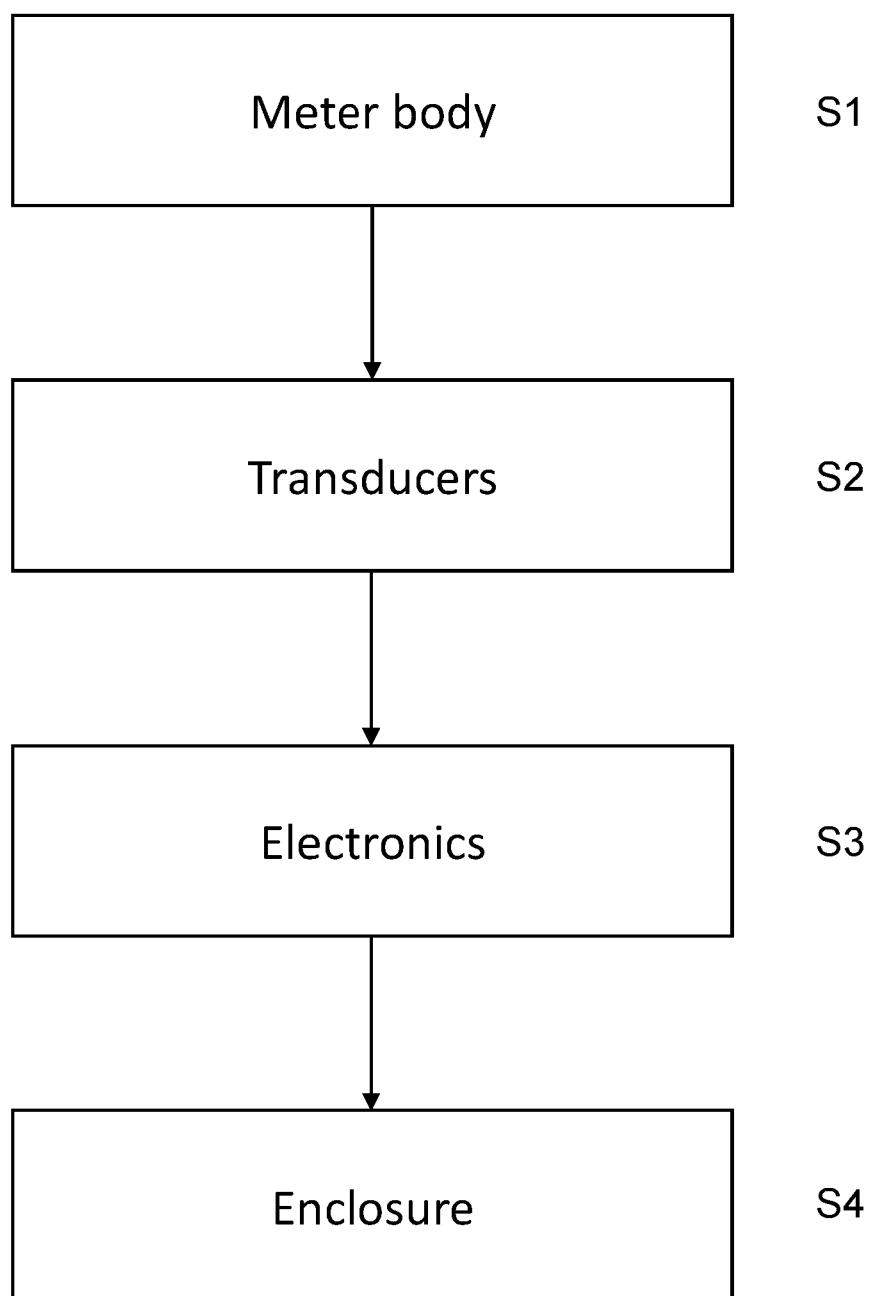


FIG. 8

Ultrasonic Liquid Flow Meter

Technical field

The invention concerns an ultrasonic liquid flow meter and methods for making such a flow meter and for making a meter body of such a flow meter.

Background

Ultrasonic flow meters can be used to measure the flow velocity of liquids in pipes. An ultrasonic transducer emits ultrasound that travels through the liquid at an angle to the flow and is then received by a second transducer. The transit time is used to calculate the speed of the liquid flow.

There are two main types of transit-time ultrasonic liquid flow meters:

- “Clamp-on” meters, where the transducers and the electronics are external to the pipe that carries the liquid. Ultrasonic shear or lamb waves are directed from the transducer through the pipe, which are then refracted and converted to longitudinal waves that travel through the liquid in the pipe and are received by the second transducer as shear waves. Clamp-on meters can be installed onto existing pipes and the transducer location depends on the pipe parameters.
- Inline meters, which have a fixed assembly where the transducers are mounted within the meter housing and the emitted ultrasound is perpendicular to the transducer face and goes directly into the liquid. In large meter sizes (e.g. > DN100) direct paths are usually used, whereby sound travels directly from transducer to transducer without reflections. In smaller inline meters, reflectors (or “mirrors”) can be placed in the flow channel to direct the ultrasound between transducers while increasing the path length.

Both types of meters have their relative advantages and disadvantages, which also depend on the specific application. The clamp-on approach can suffer from a low signal to noise ratio (SNR) and may only allow a limited portion of the pipe cross section to be sampled. Inline meters can often provide greater SNR and allow for greater freedom in choosing ultrasound paths through the liquid, but can have significant assembly complexity, e.g. in regards to the transducer mounting location which has to provide a hermetic seal throughout the whole term of operation of the meter.

Summary of invention

The present disclosure provides an ultrasonic liquid flow meter comprising reflectors formed in the outer surface of the meter body, thereby leaving the flow channel clear and reducing the impact on the flow by the meter.

Reflectors placed inside the flow channel, by contrast, cause a pressure drop and turbulence in the flow. Such internal reflectors also introduce places for possible dirt build-up and potential space for gas build-up.

According to a first aspect of the present disclosure there is provided an ultrasonic liquid flow meter. The ultrasonic liquid flow meter (also referred to herein as “flow meter”) comprises a meter body comprising a through channel for liquid flow, and a pair of ultrasonic transducers attached to the meter body and comprising a first transducer configured to emit ultrasound through the meter body into the through channel and an second transducer configured to receive ultrasound. The flow meter further comprises one or more reflectors configured to direct ultrasound emitted by the first transducer to the second transducer, wherein each of the one or more reflectors comprises an outer surface element of the meter body.

Typically, both transducers are substantially identical and configured to both emit and receive ultrasound. In an embodiment, the second transducer is further configured to emit ultrasound through the meter body and into the through channel, and the first transducer is further configured to receive ultrasound. The one or more reflectors are configured to direct ultrasound between the first and second transducers in both directions. For example, the flow meter may comprise an electronic switch for switching each transducer between a transmit (Tx) mode and a receive (Rx) mode. When the first transducer is in Tx mode the second transducer is in Rx mode and vice versa. The flow meter can be configured to switch the transducers between Tx mode and Rx mode at a fixed frequency. In a measurement sequence, the first transducer emits a pulse of ultrasound, which is transmitted to the second transducer. After the second transducer receives the pulse of ultrasound, second transducer emits a pulse of ultrasound that is transmitted to the first transducer. The first transducer receives the pulse of ultrasound and the process can be repeated. The flow meter can be configured to measure the

transit time of ultrasound in both directions and use the transit times to determine the flow speed.

For practical reasons, the size of the flow meter may be limited. For example, the maximum size of the flow meter may be DN200 ("diametre nominal" in mm). For example, the flow meter may be configured for a standard pipe size such as DN25, DN40, DN50, DN80, DN100, DN125 or DN150.

Each of the one or more reflectors may comprise an air backing. That is, for a flow meter operating in air, the reflectors can be directly formed from/in the meter body without requiring the attachment of a specific backing layer or other processing. By avoiding the use of an adhesive or other bonding method to attach a part to the meter body to form the reflector, there is one less potential point of failure of the flow meter.

Alternatively, each of the one or more reflectors may comprise such a backing layer attached to the outer surface element, wherein the backing layer has a speed of sound greater than 5000 ms^{-1} . For example, the backing layer may comprise one of steel, brass, alumina, silicon carbide and silicon nitride, which have a high speed of sound compared to many polymer materials.

Each of the first and second transducers typically comprises a piezoelectric element, which may be directly attached to the meter body. For example, a piezoelectric disc or rectangular element may be attached to an attachment area (e.g. a flat/smooth surface element at an angle α to the longitudinal axis of the flow meter) by an adhesive. When excited, the piezoelectric element emits ultrasound in a direction perpendicular to the plane of the attachment area. In general the piezoelectric element will have a finite beam width, but with a maximum along an axis substantially perpendicular to the attachment area. The piezoelectric element may have a through thickness fundamental resonance mode at a frequency in the range of 1 MHz to 3 MHz, or in the range of 1 MHz to 2 MHz, for example at about 1.25 MHz. In some embodiment, the first and/or second transducer may comprise a plurality of separate piezoelectric elements attached directly to the meter body. For example, the first and/or second transducer may comprise a plurality of strips (rectangular blocks) in a linear array. The piezoelectric element(s) can be potted in a recess of the meter body. For example, the meter body may comprise sidewalls surrounding the piezoelectric element(s), which can be filled with a potting material such

as a hard setting epoxy. Potting the elements can provide stability and protect the transducers from the environment.

The flow meter typically also comprises electronics. The electronics is configured to drive the emitting transducer(s) and to process the received signal from the receiving transducer(s). The electronics can be housed in an enclosure together with the transducers. For example, the electronics can be configured to determine a transit time of the ultrasound travelling between the transducers.

The flow meter may comprise a cap attached to the meter body so as to enclose the one or more reflectors. The meter body may comprise side walls surrounding the reflectors to which a cap can be attached in order to form an enclosure around the reflectors. The enclosure can be left empty to provide an air backing to the reflectors. The enclosure can protect the reflectors in case the flow meter gets flooded, allowing the flow meter to continue to operate as normal whilst submerged. The cap can be attached by an adhesive, by bolts and with a gasket between the cap and the meter body, or by plastic welding for example.

The meter body is typically a single piece unit (for example formed by a single injection moulding process). Other parts, such as the transducers are attached to the single piece unit, whilst the reflector(s) are a part of the single piece unit. The electronics for the flow meter can be connected to the transducers and then enclosed together with the transducers.

In an embodiment, the outer surface element of the reflector(s) comprises a convex surface configured to focus incident ultrasound. This can be advantageous for applications where large temperature variations occur, which can lead to beam drift due to the changes in refraction angles between the meter body and the liquid in the through channel.

The meter body typically comprises a polymer material. The polymer material can provide a "soft" interface for ultrasound between the meter body and the liquid in the through channel due to a comparable speed of sound in the two media. This reduces the amount of energy loss due to internal reflections in the meter body. The polymer material

can still provide a sufficiently different speed of sound and density compared to air to allow total internal reflection at the external boundary of the meter body.

In an embodiment, the meter body is configured to provide a W path for ultrasound transmitted from the first transducer to the second transducer. In general, at least two reflectors are required (located at the troughs of the W) to provide a W ultrasound path, with the cylindrical or flat outer surface of the meter body (at the middle peak of the W) acting as a third reflector to complete the path. The one or more reflectors may comprise a pair of reflectors located on a substantially straight line parallel to the longitudinal axis of the flow meter. The surface elements of the reflectors can be angled (with respect to the longitudinal axis of the flow meter) so as provide total internal reflection and to direct the ultrasound from the emitting transducer to the receiving transducer. Both reflectors in a pair of reflectors may have the same absolute angle with respect to the longitudinal axis of the flow meter. For example, the first reflector may be the mirror image of the second reflector (with a mirror plane perpendicular to the longitudinal axis of the flow meter). The angle of the reflectors may be in the range of 5° to 20° , and generally depend on the size of the flow meter (e.g. as defined by the inner diameter of the through channel), the material of the meter body and the type of liquid and operational temperature (which together determine the angle of refraction). A larger angle (e.g. $>20^{\circ}$) can be problematic when using injection moulding to manufacture the meter body, and may cause the inclusion of voids in the meter body.

In other embodiments, a V path may be sufficient, in which case the flow meter may comprise a single reflector to direct ultrasound between the pair of ultrasonic transducers. For the V path, the reflector may not be angled (with respect to the longitudinal axis of the flow meter), but may instead be provided by a different thickness of the meter body compared to the surrounding meter body. In this case, the thickness of the meter body is configured so that ultrasound reflected from the surface element constructively interferes with ultrasound reflected from the internal surface of the through channel (i.e. the path difference is a whole number of wavelengths).

The flow meter may comprise one or more further pairs of ultrasonic transducers, wherein the one or more reflectors are configured to direct ultrasound between the transducers of each further pair. Each pair of transducers may be associated with its own set of one or more reflectors to provide an ultrasound path (e.g. W or V path) or more

than one pair of transducers may be associated with the same set of reflectors. An advantage over clamp-on meters is that embodiments provided herein can be configured for multiple-path measurements in chordal planes as well as in the central (diametral) plane.

The through channel can comprise an unbroken surface, which may be substantially cylindrical. Since both the reflectors and the transducers can be external, no components or openings in the inner surface of the through channel are required. This can reduce the pressure drop normally associated with a flow meter.

According to a second aspect there is provided a method of manufacturing a meter body of an ultrasonic liquid flow meter. The meter body may be the meter body of the flow meter according to the first aspect. The method comprises injection moulding the meter body. The meter body comprises a through channel for liquid flow, a pair of attachment areas for attaching a pair of ultrasonic transducers to the meter body and one or more reflectors configured to direct ultrasound between the attachment areas, wherein each of the one or more reflectors comprises an outer surface element of the meter body.

The attachment areas for the transducers and the surface elements of the one or more reflectors can be defined by the injection mould, which is filled by extruding molten plastic under pressure and then cooled to harden. The size and angle of the attachment areas is limited by the injection moulding process (to avoid voids).

According to a third aspect there is provided a method of manufacturing an ultrasonic liquid flow meter. The method comprises forming a meter body according to the method of the second aspect, and attaching a pair of ultrasonic transducers to the attachment areas of the meter body, wherein the pair of ultrasonic transducers comprises a first transducer for emitting ultrasound through the meter body and into the through channel and a second transducer for receiving ultrasound.

The method may further comprise attaching a cap to the meter body so as to enclose the one or more reflectors. In an embodiment, the method further comprises attaching a backing layer to the one or more reflectors.

Brief description of the drawings

Figure 1 shows a schematic cross section of a flow meter with a W path;

Figure 2 shows a schematic cross section of another flow meter with enclosed reflectors;

Figure 3 shows a schematic cross section of another flow meter with backing layers attached to the reflectors;

Figures 4A and 4B shows schematic diagrams of a flow meter;

Figures 5A and 5B show schematic diagrams of a flow meter with two transducer pairs;

Figure 6 shows a schematic diagram of a flow meter with a V path;

Figure 7 shows a schematic diagram of a flow meter including transducer electronics; and

Figure 8 shows a flow diagram illustrating some steps of a method of making a flow meter.

Detailed description

Figure 1 shows a schematic cross section of a part of an ultrasonic liquid flow meter 2. The flow meter may be configured for a standard pipe size such as DN25, DN40, DN50, DN80, DN100, DN125 or DN150. The flow meter 2 comprises a meter body 4 with a through channel 5 for liquid flow and comprising two attachment areas 6a, 6b for a pair of ultrasonic transducers 8a, 8b. At the attachment areas 6a, 6b are part of the outer surface 7 of the meter body 4. The attachment areas 6a, 6b are substantially flat to provide a good bonding surface for the transducers 8a, 8b.

The attachment areas 6a, 6b are at an angle α with respect to the longitudinal axis (parallel to the flow direction) of the meter body 4. The angle α of the attachment areas 6a, 6b is perpendicular to the ultrasound path 10 in the flow meter 2. The transducers 8a, 8b comprise a sound-emitting element comprising a piezoelectric material such as a PZT disc. The transducers may operate in a thickness mode at a frequency in the range of 1 MHz to 3 MHz for example.

The flow meter 2 further comprises two reflectors 12a, 12b. The reflectors 12a, 12b comprise respective surface elements of the outer surface 7 of the meter body 4. The reflectors 12a, 12b are provided by the material and external shape of the meter body 4.

The meter body comprises a polymer material and the reflectors 12a, 12b have an air backing. Due to the difference in the speed of sound in the polymer material of the meter body 4 and the air, the reflectors 12a, 12b can provide total internal reflection (TIR) of ultrasound in the ultrasound path 10 between the transducers 8a, 8b.

The surface element of each reflector 12a, 12b is at an angle β to the longitudinal axis of the meter 2. The meter body 4 is configured to provide a W path for ultrasound transmitted between the pair of ultrasonic transducers 8a, 8b. For small meters, the longer path can increase the accuracy due to the proportionally greater shift in transit time between upstream signals and downstream signals.

The through channel 5 is defined by the inner surface 13 of the meter body 4. Since both the transducers 8a, 8b and the reflectors 12a, 12b are external to the through channel 5, the inner surface is unbroken and substantially cylindrical throughout the meter 2. There are no apertures in the inner surface 13 for transducers to access the flow, as in conventional (wetted) inline meters. There are also no protrusions out of the inner surface 13 e.g. due to transducers or internal reflectors or other features in the through channel 5. Hence, the flow meter 2 leaves the flow substantially uninterrupted.

In use, the first transducer 8a emits ultrasound in a direction perpendicular to the transducer face into the meter body 4. The ultrasound is refracted at the interface between the meter body 4 and the through channel 5 as it enters the liquid. The ultrasound is transmitted through the liquid and enters the meter body 4 (on the other side) where it is again refracted at the interface between the through channel 5 and the meter body 4. The ultrasound travels through the meter body 4 to the first reflector 12a, which reflects the ultrasound back through the meter body 4 and into the through channel 5. The ultrasound is reflected from the meter body 4 to the second reflector 12b, which directs the ultrasound to the second transducer 8b. The second transducer 8b receives the ultrasound. Typically, the transmitting and receiving transducers 8a, 8b are then electronically switched around to sample the other direction of flow. A typical measurement sequence includes transmission from the first transducer 8a to the second transducer 8b and then immediate reversal and transmission from the second transducer 8b to the first transducer 8a, regardless of direction of flow. Hence the flow meter can be agnostic to the flow direction. That is both transducers 8a, 8b can be configured to

transmit and receive ultrasound. The difference in transit time between the upstream and downstream measurements can be used to determine the speed of the liquid flow.

The disclosed liquid meter 2 comprises transducers and reflectors that are integrated in the meter body 4. Moreover, the reflectors 12a, 12b are part of the external meter boundary and do not interfere with the liquid flow. The meter body 4 can then be produced as a single injection moulded piece that is gas-tight by design. The piezoelectric elements of the transducers 8a, 8b can be attached to the external boundary of the meter body 4 (not in contact with the liquid in the through channel 5), with the use of an adhesive or mechanical fastening. The region where the piezoelectric elements are attached is typically potted as part of the assembly. For example, the region may be potted with a hard setting or flexible material such as polyurethane, which can provide stability and environmental protection and transducer damping. For example, the material may be in the range of 60 to 85 Shore D on the Shore hardness scale.

Figure 2 shows a part of a similar flow meter 2. The same reference numerals have been used in different figures to denote similar or equivalent features in order to aid understanding and are not intended to limit the illustrated examples. The meter body 4 comprises side walls 14 around the reflectors 12a, 12b. The side walls 14 are integral with the meter body 4 (i.e. formed from the meter body rather than attached to the meter body). For example, the meter body 4, including the sidewalls 14, may be formed by plastic injection moulding. The flow meter further comprises a cap 16 attached to the side walls 14 so as to enclose the reflectors 12a, 12b. The enclosure 17 formed by the side walls 14 and the cap 16 can provide environmental protection. For example, if the meter gets flooded, the enclosure 17 maintains the air backing of the reflectors 12a, 12b, thereby allowing the flow meter 2 to continue to operate as normal. In other embodiments, the enclosure 17 may be filled with a porous material, such as a polymer foam, to provide stability without significantly changing the properties of the reflectors 12a, 12b. The flow meter 2 may comprise a similar enclosure to house the transducers 8a, 8b and the transducer electronics (not shown).

Figure 3 shows a part of a similar flow meter 2, wherein the reflectors further comprise a backing layer 18. The backing layer 18 may comprise a material having a speed of sound that is significantly higher than that of the material of the meter body 4. For example,

when the meter body comprises a polymer material, the backing layer 18 may comprise alumina. The backing layer 18 is directly attached to the meter body 4 by an adhesive.

Figures 4A and 4B show different perspective views of a meter body 4, which may be the meter body 4 of the flow meter 2 described in relation to Figure 1 above. The meter body 4 comprises a through channel 5 formed by inner wall 13. The outer surface 7 of the meter body 4 has a shape that provides attachment areas 6a, 6b for attaching ultrasonic transducers (not shown) and to provide reflectors 12a, 12b. The through channel 5 has an overall cylindrical shape with flattened areas along the top and bottom, corresponding to the positions of the attachment areas 6a, 6b and the reflectors 12a, 12b respectively.

Figures 5A and 5B show different perspective views of another meter body 4 comprising further attachment surfaces 6c, 6d for attaching further pair of ultrasonic transducers (not shown). Further pairs of transducers can be used to sample a greater portion of the cross section of flow in the through channel 5, which can allow for more accurate volumetric flow determination. Hence, the meter body can be configured for measurements in the chordal plane. The reflectors 12a, 12b are configured to direct ultrasound from both pairs of transducers (when in use). In other embodiments, further reflectors may be provided to direct ultrasound from respective transducer pairs.

Figure 6 shows a schematic cross section of a meter body 4 having a V path. The meter body comprises through channel 5 defined by inner wall 13. A single reflector 12 is configured to direct ultrasound between a pair of transducers attached to the attachment surfaces 6a, 6b. The reflector 12 comprises a surface element of the outer surface 7 of the meter body 4. The reflector 12 can be configured so that the path length in the meter body 4 corresponds to an integer number of wavelengths, thereby providing constructive interference with ultrasound reflected directly from the inner wall 13.

The material of the meter body 4 can be selected based on application and in particular based on the liquid. For water, a PPE+PS blend with glass fibre reinforcement (e.g. up to 30%) may be used, to provide high strength, compatibility with drinking water and sufficient ultrasonic signal strength. This material has a relatively low speed of sound (~ 2200 m/s) and low attenuation. For other applications and liquids (such as glycol, mineral oils, acids, heavy oil, petroleum etc.) other engineering polymers can be used

e.g. PEEK, HDPE, PPS, PBT to ensure chemical resistance. PTFE with glass reinforcement may be advantageous as it has a low speed of sound to match the liquids, but can be difficult to manufacture in the desired shape.

Figure 7 shows a schematic cross section of a part of an ultrasonic liquid flow meter 2. The flow meter 2 comprises a meter body 4 with a through channel 5 for liquid flow and comprising two attachment areas 6a, 6b for a pair of ultrasonic transducers 8a, 8b. At the attachment areas 6a, 6b are part of the outer surface 7 of the meter body 4. The attachment areas 6a, 6b are substantially flat to provide a good bonding surface for the transducers 8a, 8b.

The attachment areas 6a, 6b are at an angle α with respect to the longitudinal axis (parallel to the flow direction) of the meter body 4. The angle α of the attachment areas 6a, 6b is perpendicular to the ultrasound path 10 in the flow meter 2. The transducers 8a, 8b comprise a sound-emitting element comprising a piezoelectric material such as a PZT disc.

The transducers may operate in a thickness mode at a frequency in the range of 1 MHz to 3 MHz. The flow meter 2 further comprises three reflectors 12a, 12b, 12c. Two bottom reflectors 12a, 12b (at the troughs of the W path) and one top reflector 12c (at the middle peak of the W path). The reflectors 12a, 12b, 12c comprise respective surface elements of the outer surface 7 of the meter body 4. The reflectors 12a, 12b, 12c are provided by the material and external shape of the meter body 4 together with the backing material (air). The meter body 4 comprises a polymer material and the reflectors 12a, 12b, 12c have an air backing. Due to the difference in the speed of sound in the polymer material of the meter body 4 and the air, the reflectors 12a, 12b, 12c can provide total internal reflection (TIR) of ultrasound in the ultrasound path 10 between the transducers 8a, 8b.

The surface element of the (bottom) reflectors 12a, 12b is at an angle β to the longitudinal axis of the meter 2, while the surface element of the third reflector 12c is substantially parallel to the longitudinal axis. The meter body 4 is configured to provide a W path for ultrasound transmitted between the pair of ultrasonic transducers 8a, 8b. For small meters, the longer path can increase the accuracy due to the proportionally greater shift in transit time between upstream signals and downstream signals.

The through channel 5 is defined by the inner surface 13 of the meter body 4. Since both the transducers 8a, 8b and the reflectors 12a, 12b, 12c are external to the through channel 5, the inner surface is unbroken and substantially cylindrical throughout the meter 2. There are no apertures in the inner surface 13 for transducers 8a, 8b to access the flow, as in conventional (wetted) inline meters. There are also no protrusions out of the inner surface 13 e.g. due to transducers or internal reflectors or other features in the through channel 5. Hence, the flow meter 2 leaves the flow substantially uninterrupted.

The meter body 4 comprises side walls 14a around the (bottom) reflectors 12a, 12b, and sidewalls 14b around the pair of ultrasound transducers 8a, 8b and around the (top) reflector 12c. The side walls 14a, 14b can be integral with the meter body 4 (i.e. formed from the meter body rather than attached to the meter body). For example, the meter body 4, including the sidewalls 14a, 14b, may be formed by plastic injection moulding. The flow meter further comprises caps 16a, 16b attached to the side walls 14a, 14b so as to enclose the reflectors 12a, 12b, 12c and the transducers 8a, 8b.

The enclosure 17a, formed by the side walls 14a and the cap 16a, can provide environmental protection for the (bottom) reflectors 12a, 12b. For example, if the meter gets flooded, the enclosure 17a maintains the air backing of the (bottom) reflectors 12a, 12b, thereby allowing the flow meter 2 to continue to operate as normal. In other embodiments, the enclosure 17a may be filled with a porous material, such as a polymer foam, to provide stability without significantly changing the properties of the (bottom) reflectors 12a, 12b.

The enclosure 17b, formed from the sidewalls 14b and cap 16b, houses the transducers 8a, 8b and the transducer electronics 20. The enclosure is filled with a material 22, such as polyurethane. A separate enclosure 24 is provided over the (top) reflector 12c to isolate the reflector 12c from the material 22 and provide an air backing to the (top) reflector 12c.

Figure 8 shows a flow diagram illustrating at least some steps of a method of making a flow meter. The method comprises making the meter body (S1), which typically comprises injection moulding the meter body as a single piece from a polymer material. The transducers are attached to the meter body (S2) and the transducer electronics connected to the transducers (S3). Optionally, the transducers can be potted. The

transducers and electronics are then capped to enclose them (S4). Since the transducers are not wetted (i.e. there is no direct access to the flow through the transducer mounting), the requirements on the enclosure integrity and stability can be lower compared to other inline meters.

The exact dimensions of the meter body can be defined by the speeds of sound in the plastic and the liquid. Energy losses come from the attenuation in the meter body and the refractive losses and the impedance mismatch between the liquid and the meter body. For this purpose, the temperature of the liquid should also be taken into account, as this will affect the speed of sound both in the meter body and in the liquid, and can therefore affect the angle of refraction for ultrasound transmitted between the meter body and the liquid. The angles of the transducers (of the transducer attachment areas) and the reflectors can be calculated so as to provide a desired signal strength at the receiving transducer and a desired path length for a given speed of sound of the liquid under test and the meter body material.

Whilst specific embodiments have been described above, it will be appreciated that other embodiments can be made that fall within the scope of the claims. Any one or more features of one embodiment may be suitably combined with the features of any of the other embodiments.

CLAIMS:

1. An ultrasonic liquid flow meter comprising:
a meter body comprising a through channel for liquid flow;
a pair of ultrasonic transducers attached to the meter body and comprising a first transducer configured to emit ultrasound through the meter body into the through channel and an second transducer configured to receive ultrasound; and
one or more reflectors configured to direct ultrasound emitted by the first transducer to the second transducer, wherein each of the one or more reflectors comprises an outer surface element of the meter body.
2. An ultrasonic liquid flow meter according to claim 1, wherein each of the one or more reflectors comprises an air backing.
3. An ultrasonic liquid flow meter according to claim 1, wherein each of the one or more reflectors comprises a backing layer attached to the outer surface element, wherein the backing layer has a speed of sound greater than 5000 ms^{-1} .
4. An ultrasonic liquid flow meter according to any one of the preceding claims, wherein each of the first and second transducers comprises a piezoelectric element directly attached to the meter body.
5. An ultrasonic liquid flow meter according to any one of the preceding claims, wherein the piezoelectric element is potted in a recess of the meter body.
6. An ultrasonic liquid flow meter according to any one of the preceding claims, wherein the flow meter comprises a cap attached to the meter body so as to enclose the one or more reflectors.
7. An ultrasonic liquid flow meter according to any one of the preceding claims, wherein the meter body is a single piece unit.
8. An ultrasonic liquid flow meter according to any one of the preceding claims, wherein the outer surface element comprises a convex surface configured to focus incident ultrasound.

9. An ultrasonic liquid flow meter according to any one of the preceding claims, wherein the meter body comprises a polymer material.
10. An ultrasonic liquid flow meter according to any one of the preceding claims, wherein the meter body is configured to provide a W path for ultrasound transmitted from the first transducer to the second transducer.
11. An ultrasonic liquid flow meter according to any one of the preceding claims, comprising one or more further pairs of ultrasonic transducers, wherein the one or more reflectors are configured to direct ultrasound between the transducers of each further pair.
12. An ultrasonic liquid flow meter according to any one of the preceding claims, wherein the through channel comprises an unbroken and substantially cylindrical surface.
13. A method of manufacturing a meter body of an ultrasonic liquid flow meter, the method comprising:
 - injection moulding the meter body, wherein the meter body comprises a through channel for liquid flow, a pair of attachment areas for attaching a pair of ultrasonic transducers to the meter body and one or more reflectors configured to direct ultrasound between the attachment areas, wherein each of the one or more reflectors comprises an outer surface element of the meter body.
14. A method of manufacturing an ultrasonic liquid flow meter, the method comprising:
 - forming a meter body according to claim 13;
 - attaching a pair of ultrasonic transducers to the attachment areas of the meter body, wherein the pair of ultrasonic transducers comprises a first transducer for emitting ultrasound through the meter body and into the through channel and a second transducer for receiving ultrasound.
15. A method according to claim 14, further comprising attaching a cap to the meter body so as to enclose the one or more reflectors.

16. A method according to claim 14 or 15, further comprising attaching a backing layer to the one or more reflectors.

CLAIMS:

1. An ultrasonic liquid flow meter comprising:
a meter body comprising a through channel for liquid flow;
a pair of ultrasonic transducers attached to the meter body and comprising a first transducer configured to emit ultrasound through the meter body into the through channel and an second transducer configured to receive ultrasound, wherein each of the first and second transducers comprises a piezoelectric element that is potted in a recess of the meter body; and
one or more reflectors configured to direct ultrasound emitted by the first transducer to the second transducer, wherein each of the one or more reflectors comprises an outer surface element of the meter body.
2. An ultrasonic liquid flow meter according to claim 1, wherein each of the one or more reflectors comprises an air backing.
3. An ultrasonic liquid flow meter according to claim 1, wherein each of the one or more reflectors comprises a backing layer attached to the outer surface element, wherein the backing layer has a speed of sound greater than 5000 ms^{-1} .
4. An ultrasonic liquid flow meter according to any one of the preceding claims, wherein the piezoelectric element is directly attached to the meter body.
5. An ultrasonic liquid flow meter according to any one of the preceding claims, wherein the flow meter comprises a cap attached to the meter body so as to enclose the one or more reflectors.
6. An ultrasonic liquid flow meter according to any one of the preceding claims, wherein the meter body is a single piece unit.
7. An ultrasonic liquid flow meter according to any one of the preceding claims, wherein the outer surface element comprises a convex surface configured to focus incident ultrasound.

8. An ultrasonic liquid flow meter according to any one of the preceding claims, wherein the meter body comprises a polymer material.
9. An ultrasonic liquid flow meter according to any one of the preceding claims, wherein the meter body is configured to provide a W path for ultrasound transmitted from the first transducer to the second transducer.
10. An ultrasonic liquid flow meter according to any one of the preceding claims, comprising one or more further pairs of ultrasonic transducers, wherein the one or more reflectors are configured to direct ultrasound between the transducers of each further pair.
11. An ultrasonic liquid flow meter according to any one of the preceding claims, wherein the through channel comprises an unbroken and substantially cylindrical surface.
12. A method of manufacturing an ultrasonic liquid flow meter, the method comprising:
- forming a meter body, wherein forming the meter body comprises injection moulding the meter body, wherein the meter body comprises a through channel for liquid flow, a pair of attachment areas for attaching a pair of ultrasonic transducers to the meter body and one or more reflectors configured to direct ultrasound between the attachment areas, wherein each of the one or more reflectors comprises an outer surface element of the meter body;
 - attaching a pair of ultrasonic transducers to the attachment areas of the meter body, wherein the pair of ultrasonic transducers comprises a first transducer for emitting ultrasound through the meter body and into the through channel and a second transducer for receiving ultrasound, wherein each of the first and second transducers comprises a piezoelectric element; and
 - potting the piezoelectric elements in a recess of the meter body.
13. A method according to claim 12, further comprising attaching a cap to the meter body so as to enclose the one or more reflectors.

14. A method according to claim 12 or 13, further comprising attaching a backing layer to the one or more reflectors.



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Examiner: Ms Danielle Jones

Claims searched: 1-16

Date of search: 31 October 2023

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1, 2, 4, 7-15.	US2014/0174561 A1 (ASAHI ORGANIC CHEM IND) Whole doc. is relevant, but see figs. 4A-4C, 5A and paras 40, 45, 46, 49, 52 and 54 at least.
X	1, 2, 4, 6-15.	JP2020046315 A (FUJI ELECTRIC CO LTD) Whole doc. is relevant, but see at least figs and paras 25-35 and 47-53.
X	1, 3, 4, 6-9, 12-16.	JP S61132824 A (FUJI ELECTRIC CO LTD) Whole doc. is relevant, but see figs 1 and 3.
X	1, 3, 4, 6, 7, 9-16.	US6418796 B1 (BAUMOEL JOSEPH) Whole doc. is relevant.
X	1-4, 6-10, 12-16.	JP2011112499 A (ATSUDEN CORP) Whole doc. is relevant.
A,E	-	WO2023/139116 A1 (HUBA CONTROL AG)

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^X :

Worldwide search of patent documents classified in the following areas of the IPC

G01F

The following online and other databases have been used in the preparation of this search report

WPI, EPODOC, Patent Fulltext



International Classification:

Subclass	Subgroup	Valid From
G01F	0001/667	01/01/2022
G01F	0001/66	01/01/2022