

## ULTRASONIC FLOWMETER

This invention relates to an ultrasonic flowmeter with a measuring tube through which flows a medium and which, viewed in its cross section, has a bipartite split circumference forming two halves, and with two pairs of ultrasonic converters, each with an associated ultrasound reflector, which ultrasonic converters of each ultrasonic converter pair are mounted on a common circumferential half in a mutually offset position as viewed in the longitudinal direction of the measuring tube, while the ultrasound reflector for each pair of ultrasonic converters is positioned on the other, opposite circumferential half of the measuring tube between the two ultrasonic converters, in such fashion that an ultrasound signal emitted by one ultrasonic converter of an ultrasonic converter pair travels along a V-shaped signal path via the ultrasound reflector of the associated ultrasonic converter pair to the other ultrasonic converter of that ultrasonic converter pair.

The measuring accuracy of ultrasonic flowmeters generally tends to deteriorate when the medium passing through the measuring tube flows unevenly, thus deviating from a fully developed laminar or turbulent flow pattern. Such irregularities may be due to changing pipe diameters or bends along the flow path of the medium. These irregularities are generally differentiated among three categories, to wit: axial disturbances, tangential disturbances such as vortices, and radial disturbances. Tangential and radial disturbances do not contribute to a change in the actual volume flow rate. They do, however, affect ultrasonic measurements, as will be explained below.

An ultrasonic flowmeter typically encompasses at least two ultrasonic converters, together constituting an ultrasonic converter pair and mounted in a mutually offset position in the direction of the flow. One of the ultrasonic converters emits an ultrasound signal that passes through the flowing medium and is received by the other ultrasonic converter. The system design usually provides for the other ultrasonic converter to be able on

its part to transmit an ultrasound signal that is received by the first ultrasonic converter. In this fashion, ultrasound signals alternately pass through the flowing medium in or against the direction of flow. The entrainment effect of the flowing medium results in different runtimes in and, respectively, against, the flow direction. Where the length and the angle of the acoustic path relative to the flow direction are known, the runtimes in and against the flow direction permit a determination of the flow rate of the medium.

If a pipeline includes, for instance, an upward or downward bend followed by a bend to the right or left, the flow pattern can be expected to be subject to axial as well as tangential irregularities. Moreover, the tangential disturbance is likely to add another speed component along the acoustic measuring path, thus falsifying the runtimes on the basis of which the overall flow rate is determined.

To date, the approach for a solution to this problem has been to employ a minimum of two mutually intersecting measuring paths in one common plane. If the angles of the two measuring paths in the direction of flow are identical, the undesirable tangential and radial speed components can be eliminated by averaging the flow rates determined along those two paths.

One drawback lies in the fact that at least twice as many ultrasonic converters are needed. Accommodating additional ultrasonic converters in the measuring tube usually requires additional converter pockets in the wall of the measuring tube which, in turn, adds further flow disturbances.

Another approach to solving the above-described problem has been to use V-shaped signal paths. The method employed provides for the two ultrasonic converters of an ultrasonic converter pair to be mounted on one common side of the measuring tube, with an ultrasound reflector positioned on the opposite side of the measuring tube. Depending on the curvature of the measuring tube in the respective plane, such an ultrasound reflector may, in fact, be constituted of the inner wall of the measuring tube itself,

or a separate ultrasound reflector may be installed for instance in the form of a flat plate. This is part of the prior art and also applies to the invention described further below.

5 In this case, an ultrasonic signal emitted by an ultrasound converter travels along a V-shaped signal path via the ultrasound reflector to the other ultrasound converter of the ultrasonic converter pair. Similarly, an ultrasonic signal can be transmitted in the opposite direction. As stated above, this makes for a configuration that permits the elimination of the tangential and radial components through an averaging process. As one major advantage of this solution, no additional ultrasound converters are needed.

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US 200410011141 describes an ultrasonic flowmeter of the type described above. That device uses multiple V-shaped signal paths extending along mutually parallel planes. The ultrasound converter pairs and, respectively, the ultrasound reflectors are mounted on different sides of the measuring tube in the ultrasonic flowmeter. One advantage of that design is that at least the uppermost and the bottom-most V-shaped signal paths can be positioned at only a small maximum distance from the inner wall of the measuring tube. It has, in fact, been found that a minimal distance from the inner wall of the measuring tube is conducive to improved measuring accuracy since this type of signal path permits highly precise detection, and thus elimination, especially of axial irregularities. Moreover, jointly positioning all of the ultrasound converters on one single side of the measuring tube facilitates maintenance, especially when the measuring tube is accessible only with great difficulty and perhaps only from one side.

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Using multiple V-shaped signal paths in mutually parallel planes, as described above, has proved to be substantially more effective in eliminating radial and tangential flow disturbances than is attainable with the conventional signal-path configurations referred to above. However, tests have revealed that there is still an error rate of about 0.15%.

It is, therefore, the objective of this invention to introduce an ultrasonic flowmeter which permits a nearly complete elimination of the tangential and radial disturbances in the measurement of the flow rate.

5 For an ultrasonic flowmeter as first described above, this objective is achieved by positioning the first ultrasound converter pair and the second ultrasound reflector on one circumferential half of the measuring tube and the second ultrasound converter pair and the first ultrasound reflector on the other circumferential half.

10 In other words, according to the invention, the ultrasound converter pairs are mounted on mutually opposite sides and the ultrasonic signals of one ultrasound converter pair are emitted from one side and the ultrasonic signals of the other ultrasound converter pair are emitted from the other side into the flowing medium. This novel configuration is based on the realization that the error remaining in the elimination of the  
15 tangential and radial disturbances essentially derives from the fact that in the axial direction, these disturbances are not constant. The proposed configuration of the signal paths, however, can to an essentially total extent eliminate that residual error, as will be explained further below.

20 It should be pointed out at this juncture that positioning an ultrasound converter and, respectively, an ultrasound reflector "on" a circumferential half of such a system refers to any arrangement that permits the transmission, reception and, respectively, the reflection of ultrasonic signals in the area of the inner wall of the measuring tube.

25 Also, the term "V-shaped signal path" refers to any form of signal paths obtainable by mutually offsetting the ultrasound converters of the ultrasound converter pair in the flow direction and, viewed in the flow direction, by positioning the ultrasound reflector at a point between them. In particular, a "V-shaped" signal path does not require a specific angle between the legs of the "V" or an identical length of the legs.

In principle, it is possible for the two V-shaped signal paths to extend along the same plane. In a preferred embodiment of the invention, however, the two V-shaped signal paths extend along different planes. As another preferred feature, the two different planes do not intersect within the measuring tube. Most desirably, the different planes  
5 extend parallel to each another.

The advantages offered by the invention as stated above are already achieved with only two ultrasound converter pairs. A preferred embodiment of the invention, however, includes at least one additional pair of ultrasound converters with an associated ultra-  
10 sound reflector for creating an additional V-shaped signal path. Especially preferred is a configuration comprising multiple additional ultrasound converter pairs, permitting the creation of one each V-shaped signal path in several mutually different and preferably parallel planes, in which case the ultrasound converters for neighboring signal paths are positioned on different circumferential halves of the measuring tube. Viewed in the radial  
15 direction of the measuring tube, the result is an array of V-shaped signal paths whose open ends and vertices alternately appear on one or the other of the two circumferential halves.

In one preferred embodiment of the invention, two ultrasound reflectors, viewed  
20 in the longitudinal direction of the measuring tube, are spaced apart by not more than the maximum distance between the two ultrasound converters of an ultrasound converter pair. Most desirably, all ultrasound reflectors, viewed in the longitudinal direction of the measuring tube, are arranged over the same length of the measuring tube.

25 Apart from the objective of the invention specified above, it would often be necessary to equip the ultrasonic flowmeter with a diagnostic function capable of indicating whether a proper measuring operation is being maintained.

For the ultrasonic flowmeter first described above, this is accomplished by pro-  
30 viding a third ultrasound converter pair with a corresponding ultrasound reflector for cre-

ating a V-shaped signal path that extends along a plane which intersects the other two planes within the measuring tube.

Thus, according to the invention, a third signal path extends at an angle other than  
5 zero degrees relative to the other two planes in a manner whereby it intersects the other two signal-path planes within the flowing medium. This permits a diagnostic function by means of which it is possible, for example, to determine whether dirt has accumulated on the bottom of the measuring tube.

10 As a result of any such dirt accumulation, a point of reflection in that area would shift toward the center of the measuring tube, reducing the length of the acoustic path. It follows that, if in the course of the measuring operation, a diminishing runtime of that third signal path intersecting the other two planes is detected, it may be an indication of an undesirable dirt accumulation. In addition, providing a third V-shaped signal path as  
15 described, intersecting the other two planes within the measuring tube, permits the additional capture of a flow value and thus further enhances the accuracy of the flow measurements.

Specifically, in a preferred configuration according to the invention, the other two  
20 planes do not intersect within the measuring tube. Most desirably, the other two planes extend parallel to each other while the third plane extends in a direction perpendicular to these other two planes. In a preferred embodiment of the invention, the longitudinal axis of the measuring tube extends within that third plane.

25 In another preferred implementation of the invention, it is equally possible, however, to provide a fourth ultrasound converter pair with an associated ultrasound reflector for creating a V-shaped signal path which signal path extends along a plane that intersects the other two planes within the measuring tube, in which case the third plane and the fourth plane each extend at an angle other than  $90^\circ$  relative to the first plane and the sec-

ond plane, but not parallel to each other. In this fashion the aforementioned diagnostic function may be expanded to monitor, for instance, several points of reflection.

Other preferred design variations are obtainable, analogous to the configurational possibilities described above in connection with the first inventive solution, especially in terms of the inclusion of additional ultrasound converter pairs specifically for creating V-shaped signal paths in varying but, preferably, mutually parallel planes.

Finally, this invention relates to an ultrasonic flowmeter with a measuring tube through which flows a medium and which, viewed in its cross section, has a bipartite split circumference forming two halves, and comprising at least one pair of ultrasonic converters with an associated ultrasound reflector, which ultrasonic converters of each ultrasonic-converter pair are mounted on a common circumferential half in a mutually offset position as viewed in the longitudinal direction of the measuring tube, while the ultrasound reflector for each pair of ultrasonic converters is positioned on the other, opposite circumferential half of the measuring tube between the two ultrasonic converters, in such fashion that an ultrasound signal emitted by one ultrasonic converter of an ultrasonic converter pair travels along a V-shaped signal path via the ultrasound reflector of the associated ultrasonic converter pair to the other ultrasonic converter of that ultrasonic converter pair.

As has been mentioned, the ultrasound converters are usually accommodated in converter pockets that may be provided in the wall of the measuring tube. This poses a problem when measuring the flow of gas with a liquid component which can deposit itself in the converter pockets, potentially leading to undesirable situations. If, for example, a drop of water is deposited in a converter pocket, that drop could form a bridge between the ultrasound converter and the measuring tube, causing an undesirable acoustic coupling between the converter, otherwise largely sound-insulated from the measuring tube, and that tube.

It is therefore another objective of this invention to introduce an ultrasonic flowmeter designed to avoid the above-mentioned problem.

For the ultrasonic flowmeter described above, this objective is achieved by orienting the measuring tube in a way whereby the ultrasound converter of the ultrasound converter pair is positioned in a location higher than that of the associated ultrasound reflector.

This, according to the invention, ensures that the converter pockets provided for the ultrasound converter can point toward the interior of the measuring tube, making them self-draining for liquid and pasty substances. This design approach can be universally combined with all of the configurations described above.

A preferred embodiment of the invention comprises at least one additional ultrasound converter pair with a corresponding ultrasound reflector for creating another V-shaped signal path that extends along a plane which does not intersect the plane of the first V-shaped signal path within the measuring tube, in this case positioning the ultrasound converters of the additional ultrasound converter pair at a level higher than that of the associated ultrasound reflector. Most desirably, the planes extend parallel to one another while the ultrasound converter pairs are mounted on one circumferential half and the ultrasound reflectors are mounted on the other circumferential half of the measuring tube. As a result, the converter pockets for the ultrasound converters will self-drain as described above even in the case of multiple V-shaped signal paths.

The following will explain this invention in more detail with reference to the attached drawings.

In the drawings:

Figs. 1 a and b: schematically illustrate the concept of an ultrasonic flowmeter according to a first embodiment of the invention;

5 Figs. 2 a and b: schematically show, in a top view, the pattern of the signal paths in the ultrasonic flowmeter according to the first preferred embodiment of the invention (Fig. 2b) as compared to the prior art (Fig. 2a);

10 Figs. 3 a and b: schematically illustrate an ultrasonic flowmeter according to a second preferred embodiment of the invention;

Figs. 4 a and b: schematically illustrate an ultrasonic flowmeter according to a third preferred embodiment of the invention; and

15 Fig. 5 schematically illustrates an ultrasonic flowmeter according to a fourth preferred embodiment of the invention.

Figs. 1a and 1b represent a schematic cross-sectional and, respectively, perspective view of an ultrasonic flowmeter according to a first preferred embodiment of the invention. They only show the important invention-related components, these being a measuring tube 1 for a flowing medium, not depicted, and multiple ultrasound converter pairs 2, each with an ultrasound converter 3 and, associated with each ultrasound converter pair, an ultrasound reflector 4. The ultrasound converter pairs are alternately positioned on one or the other circumferential half of the measuring tube 1, in a manner as to create parallel planes, each with a V-shaped signal path 5. The alternating placement of the ultrasound converter pairs 2 and, correspondingly, of the ultrasound reflectors 4 on one side and, respectively, on the opposite side of the measuring tube 1 results in a pattern whereby the V-shaped signal paths 5 alternately have their open ends on one or on the other side of the tube. It should be noted that for the central signal path 5, the inner wall of the measuring tube 1 itself serves as an ultrasound reflector 4, thus not requiring a separate ultrasound reflector.

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This also applies in the schematic illustrations of Figs. 2a and 2b. The top view in Fig. 2a represents a prior-art concept with a single V-shaped signal path 5 or several V-shaped signal paths 5, all opening up to the right, however. By contrast, Fig. 2b schematically illustrates an arrangement of signal paths 5 according to the first preferred embodiment of the invention shown in Figs. 1a and 1b, whereby at least one signal path 5 opens to the right and one signal path 5 opens to the left. Tests have shown that this can substantially improve the measuring accuracy.

Figs. 3a and 3b depict in a cross-sectional and, respectively, a schematic perspective view an ultrasonic flowmeter according to a second preferred embodiment of the invention. In that ultrasonic flowmeter as well, the ultrasound converter pairs 2 and the ultrasound reflectors 4 are arranged in a way as to produce V-shaped signal paths along mutually parallel planes. Additionally in this case, another V-shaped signal path extends along a plane perpendicular to the parallel planes, to which effect, the corresponding ultrasound converters 3 are mounted in an overhead position within the measuring tube 1. The longitudinal axis of the measuring tube 1 extends in that signal plane, obviating the need for a separate ultrasound reflector 4 since the inner wall of the measuring tube 1 can serve that purpose. The same applies to the central plane of the mutually parallel signal-path planes.

This configuration permits a diagnostic function for the detection of dirt that may have accumulated on the bottom of the measuring tube 1. As has been explained above, any such dirt accumulation would shift the point of reflection, if provided in that location, toward the center of the measuring tube 1, thus shortening the acoustic path concerned. If over a period of time, the runtime of the signal path intersecting the other planes is found to be growing shorter, it may be an indication of undesirable dirt deposits. In addition, providing this V-shaped signal path that intersects the other planes within the measuring tube 1 permits the collection of one more flow value, thus further enhancing the accuracy of the flow measurement.

Fig. 4a and 4b illustrate, again in a cross-sectional and, respectively, perspective presentation, an ultrasonic flowmeter according to a third preferred embodiment of the invention. This configuration essentially permits achieving the benefits described in connection with the ultrasonic flowmeter according to the second preferred embodiment of the invention, the difference being that the mutually parallel signal-path planes are intersected not only by one but by two signal-path planes extending at an angle relative to each other. If in this case as well one common ultrasound reflector 4 is employed, the above-described diagnostic function for detecting dirt accumulations in the measuring tube 1 can be expanded to monitor several points of reflection.

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Finally, Fig. 5 is a schematic cross-sectional illustration of an ultrasonic flowmeter according to a fourth preferred embodiment of the invention. As a key aspect in this case, the ultrasound converters 3 are in each case positioned at a higher level than their associated ultrasound reflectors 4, whereby the converter pockets 6 accommodating the ultrasound converters 3 point downward. As has been explained above, this ensures a self-draining function of the converter pockets 6 for liquid and pasty substances.

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What is claimed is:

## CLAIMS

- 1    1. An ultrasonic flowmeter with a measuring tube (1) through which flows a medium and  
2    which, viewed in its cross section, has a bipartite split circumference forming two halves,  
3    and with two ultrasonic converter pairs (2), each with an associated ultrasound reflector  
4    (4), the ultrasonic converters (3) of each ultrasonic-converter pair (2) being mounted on a  
5    common circumferential half in a mutually offset position as viewed in the longitudinal  
6    direction of the measuring tube (1), while the ultrasound reflector (4) for each ultrasonic  
7    converter pair (2) is positioned on the other, opposite circumferential half in the longitu-  
8    dinal direction of the measuring tube (1) between the two ultrasonic converters (3), in  
9    such fashion that an ultrasound signal emitted by one ultrasonic converter (3) of an ultra-  
10    sonic converter pair (2) travels along a V-shaped signal path (5) via the ultrasound reflec-  
11    tor (4) of the associated ultrasonic converter pair (2) to the other ultrasonic converter (3)  
12    of that ultrasonic converter pair (2), wherein the first ultrasound converter pair (2) and the  
13    second ultrasound reflector (4) are positioned on one circumferential half of the measur-  
14    ing tube while the second ultrasound converter pair (2) and the first ultrasound reflector  
15    (4) are positioned on the other circumferential half of the measuring tube.
- 1    2. The ultrasonic flowmeter as in claim 1, wherein the two V-shaped signal paths (5) ex-  
2    tend along different planes.
- 1    3. The ultrasonic flowmeter as in claim 2, wherein the different planes do not intersect  
2    within the measuring tube (1).
- 1    4. The ultrasonic flowmeter as in claim 3, wherein the different planes extend parallel to  
2    each other.
- 1    5. The ultrasonic flowmeter as in one of the claims 1 to 4, wherein said flowmeter com-  
2    prises at least one additional ultrasound converter pair (2) with an associated ultrasound  
3    reflector (4) for creating an additional V-shaped signal path.

1 6. The ultrasonic flowmeter as in one of the claims 1 to 5, wherein, viewed in the longi-  
2 tudinal direction of the measuring tube (1), two ultrasound reflectors (4) are spaced apart  
3 by the maximum distance between two ultrasound converters (3) of an ultrasound con-  
4 verter pair (2).

1 7. The ultrasonic flowmeter as in claim 6, wherein, viewed in the longitudinal direction  
2 of the measuring tube (1), all ultrasound reflectors (4) are mounted over the same length  
3 of the measuring tube (1).

1 8. An ultrasonic flowmeter with a measuring tube (1) through which flows a medium and  
2 which, viewed in its cross section, has a bipartite split circumference forming two halves,  
3 and with two ultrasonic converter pairs (2), each with an associated ultrasound reflector  
4 (4), which ultrasonic converters (3) of each ultrasonic converter pair (2) are mounted on a  
5 common circumferential half in a mutually offset position as viewed in the longitudinal  
6 direction of the measuring tube (1), while the ultrasound reflector (4) for each ultrasonic  
7 converter pair (2) is positioned on the other, opposite circumferential half in the longitu-  
8 dinal direction of the measuring tube (1) between the two ultrasonic converters (3), in  
9 such fashion that an ultrasound signal emitted by one ultrasonic converter (3) of an ultra-  
10 sonic converter pair (2) travels along a V-shaped signal path (5) via the ultrasound reflec-  
11 tor (4) of the associated ultrasonic converter pair (2) to the other ultrasonic converter (3)  
12 of that ultrasonic converter pair (2), wherein a third ultrasound converter pair (2) is pro-  
13 vided together with an associated ultrasound reflector (4) to create a V-shaped signal path  
14 (5) which extends along a plane that intersects the other two planes within the measuring  
15 tube (1).

1 9. The ultrasonic flowmeter as in claim 8, wherein the other two planes do not intersect  
2 within the measuring tube (1).

1 10. The ultrasonic flowmeter as in claim 9, wherein the other two planes extend parallel  
2 to each other while the third plane extends in a direction perpendicular to the other two  
3 planes.

- 1 11. The ultrasonic flowmeter as in one of the claims 8 to 10, wherein the third plane en-  
2 compasses the longitudinal axis of the measuring tube (1).
- 1 12. The ultrasonic flowmeter as in one of the claims 1 to 10, wherein a fourth ultrasound  
2 converter pair (2) is provided together with an associated ultrasound reflector (4) to cre-  
3 ate a V-shaped signal path (5) which extends along a plane that intersects the other two  
4 planes within the measuring tube (1) and the third and the fourth planes each extend at an  
5 angle other than  $90^\circ$  relative to the first plane and the second plane without extending  
6 parallel to each other.
- 1 13. The ultrasonic flowmeter as in one of the claims 8 to 12, wherein the flowmeter in-  
2 corporates at least one more ultrasound converter pair (2) with an associated ultrasound  
3 reflector (4) for creating an additional V-shaped signal path (5) which signal path (5) ex-  
4 tends along a plane parallel to the first two mutually parallel planes.
- 1 14. The ultrasonic flowmeter as in one of the claims 1 to 13, wherein the measuring tube  
2 (1) is oriented in a way whereby the ultrasound converters (3) of at least one ultrasound  
3 converter pair (2) are positioned at a level higher than that of the associated ultrasound  
4 reflector (4).
- 1 15. The ultrasonic flowmeter as in claim 14, wherein the flowmeter comprises at least  
2 one further ultrasound converter pair (2) with an associated ultrasound reflector (4) for  
3 creating an additional V-shaped signal path (5) which extends along a plane that does not  
4 intersect the plane of the first V-shaped signal path (5) within the measuring tube (1), and  
5 the ultrasound converters (3) of the additional ultrasound converter pair (2) are positioned  
6 at a level higher than that of the associated ultrasound reflector (4).
- 1 16. The ultrasonic flowmeter as in claim 15, wherein the planes extend parallel to one  
2 another and that the ultrasound converter pairs (2) are positioned on one circumferential  
3 half and the ultrasound reflectors (4) are positioned on the other circumferential half of  
4 the measuring tube (1).