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## Flowmeter sensor

### Abstract


A flowmeter sensor can stably measure in a wide temperature range including one over 100° C. The flowmeter sensor includes an ultrasonic transducer, a pipe, and an acoustic prism. The acoustic prism has a bottom surface that is arranged in contact with the outer peripheral surface of the pipe and a front-side inclination surface that supports the ultrasonic transducer. The acoustic prism propagates ultrasonic waves from the ultrasonic transducer toward the fluid within the pipe. The pipe is made of a first heat-resistant resin having heat resistance in a temperature range of 90° C. to 200° C. and negative thermoacoustic characteristics in which the ultrasonic transmittance decreases as the temperature rises in such a temperature range. The acoustic prism is made of a second heat-resistant resin having heat resistance in the temperature range and positive thermoacoustic characteristics in which the ultrasonic transmittance increases as the temperature rises in such a temperature range.



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## Background/Summary

TECHNICAL FIELD

(1) The present invention relates to a flowmeter sensor.

(2) Conventionally, various ultrasonic flowmeters that measure the flow rate of liquids have been proposed as measurement devices that use ultrasonic waves. In this ultrasonic flowmeter, a flow rate measuring pipe is provided in the middle of a pipe through which liquid flows, and ultrasonic sensors are installed at upstream and downstream positions of the flow rate measuring pipe. Then,

ultrasonic waves are transmitted and received using these ultrasonic sensors, and a liquid flow rate is calculated based on the time difference between the propagation time of the ultrasonic waves propagating from the upstream side to the downstream side and the propagation time of the ultrasonic waves propagating from the downstream side to the upstream side.
(3) While various ultrasound flowmeters of this type have been proposed, there exists, for example, a clamp on type ultrasonic flowmeter sensor that can be attached to a straight-shaped pipe (as referenced in Patent Document 1).
(4) As the above-described straight-type flowmeter sensor, there has conventionally been proposed one in which a pair of acoustic prisms supporting an ultrasonic transducer are arranged by being offset in the axial direction of a pipe (see, for example, Patent Document 2).
PRIOR ART DOCUMENTS
Patent Document
(5) Patent Document 1: U.S. Pat. No. 5,927,394 Patent Document 2: U.S. Pat. No. 6,789,766
DISCLOSURE OF THE INVENTION
Problems to be Solved by the Invention
(6) However, in the conventional technology, it was possible to perform stable measurements in a relatively low temperature range from normal temperature to about 100° C., but there was a problem in a high-temperature range exceeding 100° C., the sensitivity decreased significantly, and stable measurement was impossible.
(7) The present invention has been made in view of the above problems, and an object thereof is to provide a flowmeter sensor capable of stably measuring flow velocity in a wide temperature range including a high-temperature range exceeding 100° C.
Means for Solving the Problem
(8) Therefore, based on the prediction that the cause of the decrease in sensitivity in the flowmeter sensor at a high-temperature range exceeding 100° C. lies in the characteristics of the materials used in the sensor components, the inventors of the present invention conducted extensive research. As a result, the acoustic properties of the materials used for conventional general sensor components are temperature dependent, and most of such materials have the characteristics to decrease the ultrasonic transmittance as the temperature rises (that is, negative thermoacoustic characteristics). In particular, the inventors have newly found a characteristic that the ultrasonic wave transmittance decreases significantly in a high-temperature range exceeding 100° C. In addition, in observing the proportions of lengths that individual components occupy within the entire length of the ultrasonic propagation path, it was newly discovered that the greater the proportion of length a material occupies, the more significant the impact of its thermoacoustic characteristics on the overall characteristics of the sensor. After conducting trial and error based on these findings, the inventors of the present invention have finally conceived the following inventive aspects.
(9) In order to solve the above problems, the first aspect of the present invention refers to a flowmeter sensor comprising an ultrasonic transducer that generates ultrasonic waves, a pipe through which a fluid flows, and an acoustic prism having a bottom surface that is arranged in contact with the outer peripheral surface of the pipe and a front side inclination face that supports the ultrasonic transducer, and propagates ultrasonic waves from the ultrasonic transducer toward the fluid in the pipe, wherein the pipe is made of a first heat resistant resin having heat resistance in a temperature range of 90° C. to 200° C. and a negative thermoacoustic characteristics in which the ultrasonic transmittance decreases as the temperature rises in such a temperature range, and the acoustic prism is made of a second heat-resistant resin having heat resistance in a temperature range of 90° C. to 200° C. and a positive thermoacoustic characteristics in which the ultrasonic transmittance increases as the temperature rises in such a temperature range.
(10) As such, according to the first aspect of the invention, the second heat-resistant resin having positive thermoacoustic characteristics is used for the acoustic prism, which occupies a relatively

large proportion of the total length of the ultrasonic wave propagation path. Therefore, even if the other member forming the ultrasonic wave propagation path is made of a material having negative thermoacoustic characteristics, the influence thereof is alleviated. As a result, it is possible to minimize the decrease in ultrasonic transmittance in a high temperature range exceeding 100° C. and to maintain suitable sensitivity even in such a high-temperature range. In addition, both the acoustic prism and the pipe are made of a resin material that has heat resistance in a high-temperature range of over 100° C., thus making it possible to perform measurement even when a high temperature fluid of over 100° C. is flowing.

(11) The second aspect of the present invention refers to a flowmeter sensor according to the first aspect of the present invention, wherein an ultrasonic wave propagation path is formed by the pipe and the acoustic prism; thereof, the length occupied by the acoustic prism in the entire length of the ultrasonic wave propagation path is greater than that occupied by the pipe in the entire length of the ultrasonic wave propagation path.

(12) According to the second aspect of the present invention, even if the pipe-forming material has negative thermoacoustic characteristics, by combining it with the acoustic prism made of the pipe-forming material having positive thermoacoustic characteristics, the effect of the negative thermoacoustic characteristics can be effectively mitigated.

(13) The third aspect of the present invention refers to a flowmeter sensor according to the second aspect of the present invention, wherein the second heat-resistant resin is polyether sulfone, and the first heat-resistant resin is a fluororesin that has a higher heat resistance than the second heat resistant resin.

(14) The fourth aspect of the present invention refers to a flowmeter sensor according to the first aspect of the present invention, wherein a coupling material layer is further provided in contact with the outer peripheral surface of the pipe and the bottom surface of the acoustic prism, and the coupling material layer is made of a heat resistant material having a heat resistance in the temperature range of 90° C. to 200° C.

(15) Therefore, according to the fourth aspect of the present invention, by arranging the pipe and the acoustic prism via the coupling material layer, the adhesion between the pipe and the acoustic prism is improved, and the ultrasonic waves are efficiently propagated, thus making it possible to accurately measure the flow velocity.

(16) The fifth aspect of the present invention refers to a flowmeter sensor according to the fourth aspect of the present invention, wherein the heat-resistant material has negative thermoacoustic characteristics in which the ultrasonic wave transmittance decreases as the temperature rises in the temperature range of 90° C. to 200° C.

(17) The sixth aspect of the present invention refers to a flowmeter sensor according to the fifth aspect of the present invention, wherein an ultrasonic wave propagation path is formed by the pipe, the coupling material layer, and the acoustic prism, thereof the length occupied by the acoustic prism over the entire length of the ultrasonic wave propagation path is greater than the sum of the length occupied by the pipe and the length occupied by the coupling material layer in the entire length of the ultrasonic propagation path.

(18) Therefore, according to the sixth aspect of the present invention, even if the forming material of the pipe and of the coupling material layer has negative thermoacoustic characteristics, such a forming material is combined with the acoustic prism made of the forming material having positive thermoacoustic characteristics, thus making it possible to mitigate the influence of negative thermoacoustic characteristics effectively.

(19) The seventh aspect of the present invention refers to a flowmeter sensor according to the sixth aspect of the present invention, wherein the second heat-resistant resin is polyether sulfone, and the first heat-resistant resin is a fluororesin having a higher heat resistance than the second heat-resistant resin, and the heat resistant material is a fluororubber having a higher heat resistance than the second heat-resistant resin.

(20) The eighth aspect of the present invention refers to a flowmeter sensor according to any one of the first to the seventh aspects of the present invention, wherein an intermediate portion connecting the front-side inclination face and the bottom surface of the acoustic prism has a hollow portion formed on both sides.
(21) Therefore, according to the eighth aspect of the present invention, since the width of the intermediate portion is narrowed, the area of the lower end of the intermediate portion that contacts the pipe is reduced. As a result, the lower surface of the acoustic prism comes into contact with the pipe under high contact pressure, and the ultrasonic waves emitted by the ultrasonic transducer can be efficiently and reliably incident on the pipe side. In addition, among the ultrasonic waves emitted by the ultrasonic transducer, the ultrasonic waves that do not enter the piping side are reflected by the lower surface of the acoustic prism and become reverberation, which causes noise. In this regard, with this configuration, the lower surface of the acoustic prism is less likely to be a reflecting surface, so reverberation caused by reflection from the lower surface can be reduced. Furthermore, the amount of resin material used for forming the acoustic prism can be reduced, thus making it easier to reduce the manufacturing cost.
(22) The ninth aspect of the present invention refers to a flowmeter sensor according to any one of the first to the seventh aspects of the present invention, wherein an intermediate portion connecting the front-side inclination face and the bottom surface in the acoustic prism has a width that becomes narrower toward the bottom surface side.
(23) Therefore, according to the ninth aspect of the present invention, since the width of the intermediate portion is narrowed, the area of the lower end of the intermediate portion that contacts the pipe is reduced. As a result, the lower surface of the acoustic prism comes into contact with the pipe under high contact pressure, and the ultrasonic waves emitted by the ultrasonic transducer can be efficiently and reliably incident on the pipe side. In addition, among the ultrasonic waves emitted by the ultrasonic transducer, the ultrasonic waves that do not enter the piping side are reflected by the lower surface of the acoustic prism and become reverberation, which causes noise. In this regard, with this configuration, the lower surface of the acoustic prism is less likely to be a reflecting surface, so reverberation caused by reflection from the lower surface can be reduced. Furthermore, the amount of resin material used for forming the acoustic prism can be reduced, thus making it easier to reduce the manufacturing cost.
(24) The tenth aspect of the present invention refers to a flowmeter sensor according to any one of the first to the seventh aspects of the present invention, wherein the ultrasonic transducer is made of a porous body of alkali niobate-based piezoelectric ceramics.
(25) According to the tenth aspect of the present invention, since the porous body is a ceramic having a Curie temperature of 300° C. or higher, the characteristics do not deteriorate even at 200° C. Therefore, using an ultrasonic transducer made of this material makes it possible to obtain a flowmeter sensor capable of measuring a high-temperature fluid of over 100° C. and performing an accurate measurement even in such a case.
Effects of the Invention
(26) As detailed above, according to the first to the tenth aspects of the present invention, it is possible to provide a flowmeter sensor capable of stably measuring the flow velocity in a wide temperature range including a high-temperature range exceeding 100° C.

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## Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) FIG. **1** is a perspective view showing a straight-type flowmeter sensor according to an embodiment embodying the present invention.
(2) FIG. **2** is a perspective view of the straight type flowmeter sensor of the first embodiment

viewed from another angle.
(3) FIG. **3** is an exploded perspective view showing the straight-type flowmeter sensor according to the first embodiment.
(4) FIG. **4** is an exploded side view showing the straight-type flowmeter sensor according to the first embodiment.
(5) FIG. **5** is a plan view showing members below a pair of acoustic prisms as shown in FIG. **4**.
(6) FIG. **6** is a perspective view for explaining an arrangement state of a pair of acoustic prisms.
(7) FIG. **7** (*a*) and FIG. **7** (*b*) are side views for explaining the arrangement state of a pair of acoustic prisms.
(8) FIG. **8** is a graph comparing the relationship between temperature and transmission/reception gain for each resin material.
(9) FIG. **9** (*a*) is a side view of the acoustic prism in the straight-type flowmeter sensor according to another embodiment, FIG. **9** (*b*) is a front view thereof, and FIG. **9** (*c*) is a cross-sectional view taken along the line A-A of FIG. **9** (*a*).
(10) FIG. **10** (*a*) to FIG. **10** (*c*) are cross-sectional views of the acoustic prism according to another embodiment.
MODES FOR CARRYING OUT THE INVENTION
(11) A straight type flowmeter sensor **11** according to embodiments of the present invention will be described in detail below with reference to FIG. **1** to FIG. **8**.
(12) As shown in FIG. **1** to FIG. **7** and the like, the straight-type flowmeter sensor **11** of this embodiment includes a pipe **1**, an inner case **22**, an outer case **21**, an ultrasonic transducer **64**, an acoustic prism **61**, a coupling material layer **81**, etc.
(13) The pipe **1** is a resin tube member having a circular cross-section, and at least a part thereof has a straight portion. Inside the pipe **1**, a fluid of which the flow rate is to be measured flows, and in this embodiment, a high-temperature liquid of 100° C. or higher flows. A sheet-like coupling material layer **81** is arranged on the outer peripheral surface of the pipe **1** at the position where the prism is installed.
(14) The pair of acoustic prisms **61** is a member that supports an ultrasonic transducer **64** capable of transmitting and receiving ultrasonic waves and is also a member that propagates ultrasonic waves from the ultrasonic transducer **64** toward the fluid in the pipe **1**. (See FIG. **5** to FIG. **7**, etc.). The pair of acoustic prisms **61** are arranged on the outer peripheral surface of the pipe **1** to substantially face each other and configure the permeable straight-type flowmeter sensor **11**. In addition, the pair of acoustic prisms **61** is arranged to support an ultrasonic transducer **64** in a state in which ultrasonic waves can be obliquely incident on the straight pipe **1** through which fluid flows and is offset in the axial direction d**1** of the pipe **1**.
(15) As shown in FIG. **5** to FIG. **7** and the like, the pair of acoustic prisms **61** in this embodiment have the same size and shape. Specifically, these acoustic prisms **61** have a block shape elongated in the front rear direction (left-right direction as shown in FIG. **5**) and are formed using, for example, a resin material that can efficiently transmit ultrasonic waves. A front-side inclination face **63** is formed on the front side of the acoustic prism **61** at a predetermined angle (approximately 60 degrees in this embodiment) with respect to the bottom surface **65**. A disk-shaped ultrasonic transducer **64** made of a ceramic sintered body is adhered and supported on the front-side inclination face **63**. In this embodiment, for example, the ultrasonic transducer **64** that generates ultrasonic waves of 2 MHz is used, but it is of course possible to generate ultrasonic waves of other frequencies. As the ceramic sintered body constituting the ultrasonic transducer **64** of a piezoelectric element, a porous sintered body of alkali niobate piezoelectric ceramics such as potassium sodium niobate is selected. Of course, it may also be a ceramic sintered body other than the above. The ultrasonic radiation surfaces of these ultrasonic transducers **64** are arranged in a tilted manner in the direction of the straight pipe **1**.
(16) A plurality of legs **66** are integrally protruded from a bottom surface **65** (that is, a surface

facing the pipe **1** side) of a prism body **62** constituting these acoustic prisms **61**. Although the bottom surface **65** in this embodiment is flat, it may be concavely curved so as to correspond to the shape of the outer peripheral surface of the pipe **1**. These legs **66** extend in the same direction and hold and fix the pipe **1** from both sides. In this embodiment, there are two pairs of legs **66** on the left and right sides, that is, a total of four legs, each of which has the same shape and size. The number of legs **66** is not limited to four and may be three or less or five or more. Each leg **66** is formed to have a dimension slightly shorter than the diameter of the pipe **1**. The pair of legs **66** on the front side and the pair of legs **66** on the rear side are arranged with an interval larger than the width of the legs **66**. The reason is that the legs **66** belonging to one acoustic prism **61** are arranged in the area between the legs **66** belonging to the other acoustic prism **61** with sufficient dimensions.
(17) The pair of acoustic prisms **61** are arranged with their legs **66** alternately shifted in the axial direction d**1** of the pipe **1**, so that such legs do not come into contact with other legs **66** of different acoustic prisms **61** (that is, the counterpart acoustic prism **61**). The reason for avoiding such contacts among the legs **66** is to prevent the oscillation of the ultrasonic waves emitted by the ultrasonic transducer **64** belonging to one acoustic prism **61** from being directly transmitted to the other. Also, the plurality of legs **66** are arranged so as to avoid the center of the ultrasonic beam B**1** emitted from the ultrasonic transducer **64**. The reason for this is to reduce the loss of ultrasonic oscillation due to transmission of the ultrasonic beam B**1** to the legs **66** and to avoid deterioration in measurement accuracy and sensitivity.
(18) As shown in FIG. **3** to FIG. **5**, the inner case **22** is a rectangular box-shaped container that accommodates a pair of acoustic prisms **61** inside itself to hold and fix them in the correct position with respect to the pipe **1**. Also, the inner case **22** may serve as an electromagnetic shield that protects the ultrasonic transducer **64** housed therein from the influence of magnetism. The material for forming the inner case **22** is not particularly limited, and for example, PPS, fluororesin, or the like can be used. However, when imparting a function as an electromagnetic shield, it is preferable to use a metal material having magnetic shielding properties. The inner case **22** is composed of an upper lid member **51** and a lower lid member **52**. Approximately U-shaped notch portions **54** are formed in the center of both end surfaces of the upper lid member **51** and the center of both end surfaces of the lower lid member **52**, respectively. When the upper lid member **51** is covered with the lower lid member **52**, these notches **54** form a circular pipe insertion hole.
(19) In the inner space of the inner case **22**, the pair of acoustic prisms **61** are housed in a state where pipe **1** is held and fixed from both sides. In this state, the coupling material layer **81** is interposed between the outer peripheral surface of the pipe **1** and the bottom surface **65** of the acoustic prism **61** and is arranged in contact with them. All of the surfaces of the acoustic prism **61** except for the bottom surface **65** are substantially in contact with the inner wall surface of the inner case **22**. In addition, the inner case **22** has fastening members such as set screws or the like (not shown). By tightening the set screws, the pair of acoustic prisms **61** are held and fixed to the inner case **22** and the pipe **1** so as not to be displaced. In other words, according to this embodiment, one sensor module is configured in the middle of the pipe **1** with the pair of acoustic prisms **61** having the ultrasonic transducers **64**, the coupling material layer **81**, and the inner case **22**. The upper surface of the acoustic prism **61** is pressed by tightening the set screws, thus making it possible to increase the contact pressure of the acoustic prism **61** against the pipe **1**.
(20) As shown in FIG. **1** to FIG. **5**, the outer case **21** is a rectangular box-shaped container slightly larger than the inner case **22** and serves to house and protect the inner case **22**, which is the sensor module, and the like. Although the material for forming the outer case **21** is not particularly limited, for example, PPS, fluororesin, or the like is used. The outer case **21** is composed of a lower case divided piece **31** (first-case divided piece) and an upper-case divided piece **41** (second-case divided piece).
(21) The lower case divided piece **31** has an opening on the upper surface side overall and the edge of the opening constitutes the divided surface P**1** of the outer case **21**. The lower case divided piece

**31** has a first side wall portion **31***a* only on one side. A pipe insertion portion **33** having a first insertion hole **32** protrudes from the central portion of the outer surface of the first side wall portion **31***a*. A first end portion T**1** of the pipe **1** is inserted through the first insertion hole **32**. A connector portion **34** for cable connection is provided beside the pipe insertion portion **33** on the outer surface of the first side wall portion **31***a*. As shown in FIG. **3** and the like, a rectangular frame-shaped wall portion **36** is provided in the center of the inner bottom surface of the lower-case divided piece **31**. By fitting the inner case **22** into the recess formed by the wall portion **36**, the inner case **22** is positioned and fixed to the lower case divided piece **31**. At the four corners of the inner bottom surface of the lower-case divided piece **31**, columnar bosses **35** are protruded to be used for fixing the upper-case divided piece **41** with screws. A female thread is formed in each boss **35**.
(22) On the other hand, the upper-case divided piece **41** has an opening on the lower surface side overall, and the edge of the opening constitutes the divided surface P**1** of the outer case **21**. The upper case divided piece **41** has a second side wall portion **41***a* only on one side. The second side wall portion **41***a* is positioned to face the first side wall portion **31***a* of the outer case **21**. A pipe insertion portion **43** having a second insertion hole **42** protrudes from the center of the outer surface of the second side wall portion **41***a*. A second end portion T**2** of the pipe **1** is inserted through the second insertion hole **42**. The upper case divided piece **41** differs from the lower case divided piece **31** in that it does not include the connector portion **34**, the boss portion **35**, and the wall portion **36**. Screw insertion portions **45** are formed at the four corners of the bottom surface of the upper case divided piece **41** to face the boss portions **35** of the lower case divided piece **31**, respectively. A screw **71** is inserted through each of the screw insertion portions **45**, and a screw cap **72** for hiding the screw **71** is provided.
(23) A waterproof packing **23** is attached to the interface when the lower case divided piece **31** and the upper case divided piece **41** are joined together at the divided surfaces P**1**. The waterproof packing **23** of this embodiment has a rectangular shape similar to the shape of the opening edge and is formed using a fluororesin such as FPM or the like. The waterproof packing **23** is compressed by tightening the screw **71** from the vertical direction while being arranged between the lower case divided piece **31** and the upper case divided piece **41**. As a result, no clearance is formed at the interface between the lower-case divided piece **31** and the upper case divided piece **41**. As such, the sealing property is improved, thus making it possible to waterproof the outer case **21**.
(24) Next, materials for forming the pipe **1**, the acoustic prism **61**, and the coupling material layer **81** that constitute the straight-type flowmeter sensor **11** of this embodiment will be described.
(25) In this embodiment, the pipe **1** is a tubular member with an outer diameter of several millimeters and a wall thickness of about 1 mm, made of the first heat resistant resin. The first heat resistant resin has heat resistance in a temperature range of 90° C. to 200° C. The above phrase " . . . has heat resistance in a temperature range of 90° C. to 200° C." is defined as having a glass transition point Tg of 200° C. or higher when the first heat resistant resin is an amorphous resin, for example. When the first heat resistant resin is a crystalline resin, it is defined as having both a glass transition point Tg and a melting point of 200° C. or higher. That is, the first heat resistant resin does not soften in such a temperature range and maintains stable physical properties. Separately from this, the above phrase " . . . has heat resistance in a temperature range of 90° C. to 200° C." may also be defined as having a continuous use temperature of 200° C. or higher in a no-load state. In addition, the first heat-resistant resin has negative thermoacoustic characteristics in which the transmittance of ultrasonic waves decreases (that is, the propagation attenuation increases) as the temperature rises in such a temperature range. Since the first heat-resistant resin is used for parts that come into direct contact with the fluid to be measured, it is preferable to include chemical resistance that does not deteriorate or corrode even when exposed to high-temperature, strong acid, or strong alkaline liquids.
(26) The coupling material layer **81** of this embodiment is a rectangular sheet material having a thickness of about 0.5 mm to 1 mm and is made of a heat-resistant material having heat resistance

in a temperature range of 90° C. to 200° C. The above phrase " . . . has heat resistance in a temperature range of 90° C. to 200° C." is defined such that the heat resistant material is rubber, for example, and that when the tensile strength is measured after aging for 24 hours, the temperature observed as the measured value decreases is above 200° C. Like the first heat-resistant resin, this heat resistant material has negative thermoacoustic characteristics in which the transmittance of ultrasonic waves decreases as the temperature rises in such a temperature range. In addition, it is preferable that the coupling material layer **81** has suitable elasticity for closely contacting the outer peripheral surface of the pipe **1** and the bottom surface **65** of the acoustic prism **61**.

(27) The acoustic prism **61** of this embodiment is made of a second heat resistant resin different from the first heat-resistant resin and the heat resistant material described above. The second heat-resistant resin has heat resistance in the temperature range of 90° C. to 200° C. "Having heat resistance in the temperature range" is defined as having a glass transition point Tg of 200° C. or higher when the second heat-resistant resin is an amorphous resin, for example. When the second heat-resistant resin is a crystalline resin, it is defined as having both a glass transition point Tg and a melting point Tm of 200° C. or higher. However, the heat resistance required for the second heat-resistant resin may not be as high as the heat resistance required for the first heat-resistant resin. Unlike the first heat-resistant resin and the heat-resistant material, the second heat-resistant resin has positive thermoacoustic characteristics of which ultrasonic transmittance increases (that is, propagation attenuation decreases) as the temperature rises in such a temperature range. That is, the second heat-resistant resin and the first heat-resistant resin or heat-resistant material have thermoacoustic characteristics opposite to each other.

(28) In this embodiment, as the first heat resistant resin that is the material for forming the pipe **1**, a fluororesin having a higher heat resistance than the second heat-resistant resin is selected. Specifically, PFA (perfluoroalkoxy alkanes) is selected. As the heat-resistant material for forming the coupling material layer **81**, fluororubber having higher heat resistance than the second heat-resistant resin is selected. Specifically, FKM (propylene hexafluoride-vinylidene fluoride copolymer) is selected. PES (polyether sulfone) is selected as the second heat resistant resin that is the material for forming the acoustic prism **61**.

(29) As shown in FIG. **5**, according to this straight-type flowmeter sensor **11**, an ultrasonic propagation path is formed by the pipe **1**, the acoustic prism **61** and the coupling material layer **81**. The acoustic prism **61** has a front side inclination face **63** for making ultrasonic waves obliquely enter the fluid in the pipe **1**. The incident angle increases as the tilt angle of the front side inclination face **63** of the acoustic prism **61** increases. In this case, the propagation time difference used to calculate the flow velocity and flow rate is increased, which is advantageous for improving the measurement accuracy. On the other hand, the greater the tilt angle, the longer the propagation distance within the acoustic prism **61**, thus quickly receiving the influence of the attenuation characteristics. Given such circumstances, the angle of the front-side inclination face **63** of the acoustic prism **61** is preferably 30 degrees to 70 degrees, more preferably 45 degrees to 60 degrees. With such an inclination angle, the proportion of the length occupied by the acoustic prism **61** to the total length of the ultrasonic wave propagation path becomes as large as 70 to 99%.

(30) FIG. **8** is the graph showing the test results comparing the thermoacoustic characteristics of multiple resin materials. Here, test pieces were prepared for each of a plurality of types of resin materials, and ultrasonic transducers having a resonance frequency of 2 MHz were attached to both end surfaces of the test pieces, thus transmitting and receiving ultrasonic waves by impulse driving. Then, the transmission/reception gain (dB re 1V/V) of the ultrasonic wave transmitted through the test piece was investigated in a predetermined temperature range (20° C. to 200° C.). PPS, PI, PEEK, PES, PFA, and FKM were selected as resin materials.

(31) As shown in the graph of FIG. **8**, for PPS, the transmission/reception gain showed a substantially constant maximum value in the temperature range of 20° C. to 100° C. However, when the temperature exceeded 100° C., the transmission/reception gain dropped sharply.

Regarding PI, the transmission/reception gain showed the maximum value at 20° C. but gradually decreased as the temperature increased. For PEEK, the transmission/reception gain showed the maximum value at 20° C. Still, it gradually decreased as the temperature increased, and when exceeding the temperature around 150° C., the transmission/reception gain dropped sharply. Regarding FKM, the transmission/reception gain showed the maximum value at 20° C. but gradually decreased as the temperature increased. That is, in the graph of FIG. **8**, the curves showing PPS, PI, PEEK, and FKM can all be said to be "generally downward sloping curves" in the normal temperature range of 20° C. to 200° C. As for PFA, the transmission/reception gain showed the maximum value at 60° C. but gradually decreased as the temperature increased. That is, in the graph of FIG. **8**, the curve showing PFA has a slightly upward sloping portion in a relatively low-temperature range. Still, in the temperature range of 20° C. to 200° C., which is normal temperature, it could be called a "generally downward-sloping curve." In other words, it was concluded that PPS, PI, PEEK, PFA, and FKM have "negative thermoacoustic characteristics" in which the ultrasonic transmission decreases with increasing temperature, at least in the temperature range of 90° C. to 200° C.
(32) On the other hand, PES has a low transmission/reception gain at 20° C., which is much lower than PPS, PI, and PEEK. However, the transmission/reception gain gradually increases as the temperature rises. When it reaches about 120° C., the transmission/reception gain exceeds PPS, PI, PEEK, PFA, and FKM, showing the maximum value between 150° C. and 200° C. That is, in the graph of FIG. **8**, the curve showing the PES can be called "a generally upward-sloping curve" in the normal temperature range of 20° C. to 200° C. In other words, it was concluded that, unlike PPS, PI, PEEK, PFA, and FKM, PES has a "positive thermoacoustic characteristics" in which the ultrasonic transmittance increases as the temperature rises at least in the temperature range of 90° C. to 200° C.
(33) Therefore, according to this embodiment, the following effects can be obtained. (1) According to the straight flowmeter sensor **11** of this embodiment, the pipe **1**, the acoustic prism **61**, and the coupling material layer **81** configure an ultrasonic wave propagation path from one ultrasonic transducer **64** to the other ultrasonic transducer **64**. Then, the pipe **1** is made of a first heat-resistant resin (PFA) having heat resistance in a temperature range of 90° C. to 200° C. and negative thermoacoustic characteristics in which the ultrasonic transmittance decreases as the temperature rises in such a temperature range. The acoustic prism **61** is made of a second heat-resistant resin (PES) having heat resistance in the temperature range of 90° C. to 200° C. and positive thermoacoustic characteristics in which the ultrasonic transmittance increases as the temperature rises in such a temperature range. The coupling material layer **81** is made of a heat-resistant material (FKM) having heat resistance in the temperature range of 90° C. to 200° C. and negative thermoacoustic characteristics in which the ultrasonic transmittance decreases as the temperature rises in such a temperature range.
(34) According to this embodiment, the second heat-resistant resin having positive thermoacoustic characteristics is used for the acoustic prism **61**, which occupies a relatively large proportion of the total length of the ultrasonic wave propagation path. Therefore, even if the other members (i.e., the pipe **1** and the coupling material layer **81**) forming the ultrasonic wave propagation path have negative thermoacoustic characteristics, the influence thereof is reduced. Therefore, it is possible to minimize the decrease in ultrasonic transmittance in a high-temperature range exceeding 100° C. and to maintain a suitable sensitivity even in such a temperature range. In addition, since the acoustic prism **61**, the pipe **1**, and the coupling material layer **81** all use materials having heat resistance in a high-temperature range of over 100° C., measurements can be done even when a high-temperature fluid of over 100° C. flows. As described above, according to this embodiment, it is possible to provide the straight type flowmeter sensor **11** that can stably measure the flow velocity in a wide temperature range including a high-temperature range of over 100° C. (2) According to this embodiment, the pipe **1** and the acoustic prism **61** are arranged via an elastic

coupling material layer **81**. Therefore, the adhesion between the pipe **1** and the acoustic prism **61** is improved, and ultrasonic waves can be efficiently propagated, thus making it possible to measure flow velocity accurately. (3) According to this embodiment, the straight-type flowmeter sensor **11** is configured using an ultrasonic transducer **64** made of a porous body of alkaline niobate piezoelectric ceramics. Since the porous body is a ceramic having a Curie temperature of 300° C. or higher, the properties do not deteriorate even at 200° C. Therefore, using the ultrasonic transducer **64** made of this material, the flowmeter sensor **11** that can measure a high-temperature fluid at over 100° C. and perform accurate measurements even in such a case can be obtained.

(35) Also, each of the above embodiments may be modified as follows. In each of the embodiments described above, PTFE is selected as the first heat resistant resin that is the material for forming the pipe **1**. However, the material is not limited to this. For example, PTFE (polytetrafluoroethylene), FEP (perfluoroethylene propene copolymer), or the like may be selected as another fluororesin having higher heat resistance than the second heat-resistant resin. According to each embodiment described above, FKM, a vinylidene fluoride-based fluororubber, is selected as the heat-resistant material for forming the coupling material layer **81**. However, the material is not limited to this. For example, fluororubber such as tetrafluoroethylene-propylene system (FEPM) and tetrafluoroethylene-purple vinyl ether system (FFKM) or the like may be selected. As a material for forming the coupling material layer **81**, a rubber material other than the fluororubber may be used, or a material other than the rubber material (liquid such as oil, grease, or adhesive) may also be used. According to each of the embodiments described above, PES is selected as the second heat resistant resin that is the material for forming the acoustic prism **61**. However, it is not limited to this. For example, PEF-GF30, which is obtained by adding glass fiber to PES, may also be selected. According to each of the above-described embodiments, the intermediate portion **69** connecting the front side inclination face **63** and the bottom surface **65** of the acoustic prism **61** is formed to have the same width in the horizontal direction, but it is not limited to this. For example, like the acoustic prism **61**A of the straight-type flowmeter sensor **11** of another embodiment, as shown in FIG. **9**, a hollow portion **62***a* may be formed on both side surfaces of an intermediate portion **69** connecting the front-side inclination face **63** and the bottom surface **65**. In this case, the width W**1** of the portion left after the hollow portion is preferably set to be smaller than the diameter D**1** of the ultrasonic transducer **64** and smaller than the diameter D**2** of the pipe **1** (preferably about 20% to 50% of D**2**). According to this configuration, the area of the lower end of the intermediate portion **69** in contact with the pipe **1** is reduced so that the lower surface of the acoustic prism **61**A comes into contact with the pipe **1** under high contact pressure. Therefore, the ultrasonic waves emitted by the ultrasonic transducer **64** can be efficiently and reliably incident on the pipe **1** side. For example, like the acoustic prisms **61**B, **61**C, and **61**D of another embodiment, as shown in FIG. **10**(*a*) to FIG. **10**(*c*), the intermediate portion **69** connecting the front-face inclination face **63** and the bottom surface **65** may be formed so that the width becomes narrower toward the bottom surface **65** side. In this case, the minimum width W**2** of the intermediate portion **69** is preferably set to be smaller than the diameter D**1** of the ultrasonic transducer **64** and smaller than the diameter D**2** of the pipe **1** (preferably about 20% to 50% of D**2**). With these configurations, the area of the lower end of the intermediate portion **69** that contacts the pipe **1** is reduced so that the lower surfaces of the acoustic prisms **61**B to **61**D come into contact with the pipe **1** under high contact pressure. Therefore, as in the case of FIG. **9**, the ultrasonic waves emitted by the ultrasonic transducer **64** can be efficiently and reliably incident on the pipe **1** side. According to each of the above-described embodiments, a plurality of legs **66** for holding and fixing the pipe **1** from both sides protrudes from the bottom surface **65** of the prism body **62** that constitutes the acoustic prism **61**. However, these legs may be omitted. However, in the case where the structures as shown in FIG. **9**(*a*) to FIG. **9**(*c*) and FIG. **10**(*a*) to FIG. **10**(*c*) are adopted, a plurality of legs **66** should be protruded to hold and fix the lower end of the intermediate portion **69**, which has a small area, must be brought into contact with the pipe **1** side. According to each of

the above-described embodiments, the substantially trapezoidal acoustic prism **61** in a side view is used. However, it is not limited to this. For example, an acoustic prism having a substantially triangular shape in a side view may also be used. According to each of the above-described embodiments, the present invention is embodied in the straight-type flowmeter sensor **11**. Still, it may also be embodied in a non-straight-type flowmeter sensor. According to each of the above-described embodiments, the ultrasonic transducer **64** made of potassium sodium niobate-based (alkali niobate-based) porous sintered body is used. However, it is not particularly limited to this. It is also possible to use the ultrasonic transducer **64** made of ceramic sintered body of, for example, lead zirconate titanate (PZT), barium titanate, PMN-PT (Pb (Mg.sub.1/3Nb.sub.2/3) O.sub.3—PbTiO.sub.3) single crystal, PZNT (Pb (Zn.sub.1/3Nb.sub.2/3) O.sub.3—PbTiO.sub.3) single crystal, or LiNbO.sub.3 single crystal.
(36) Besides the technical ideas of the present invention, as described above, other technical ideas to be understood are described hereinafter. (1) A flowmeter sensor comprising an ultrasonic transducer that generates ultrasonic waves, a pipe through which a fluid flows, and an acoustic prism having a bottom surface that is arranged in contact with the outer peripheral surface of the pipe and a front side inclination face that supports the ultrasonic transducer, and propagates ultrasonic waves from the ultrasonic transducer toward the fluid in the pipe, wherein a portion connecting the front-side inclination face and the bottom surface of the acoustic prism has a hollow portion formed on both side surfaces thereof. (2) A flowmeter sensor comprising an ultrasonic transducer that generates ultrasonic waves, a pipe through which a fluid flows, and an acoustic prism having a bottom surface that is arranged in contact with the outer peripheral surface of the pipe and a front side inclination face that supports the ultrasonic transducer, and propagates ultrasonic waves from the ultrasonic transducer toward the fluid in the pipe, wherein a portion connecting the front-side inclination face and the bottom surface of the acoustic prism is formed such that the width becomes narrower toward the bottom surface side. (3) A flowmeter sensor according to the above-first or second technical idea, wherein a plurality of legs for holding and fixing the pipe from both sides are integrally protruded from the bottom surface of the prism body constituting the acoustic prism. (4) A flowmeter sensor comprising an ultrasonic transducer that generates ultrasonic waves, a pipe through which a fluid flows, and an acoustic prism having a bottom surface that is arranged in contact with the outer peripheral surface of the pipe and a front side inclination face that supports the ultrasonic transducer, and propagates ultrasonic waves from the ultrasonic transducer toward the fluid in the pipe, wherein the acoustic prism is made of a heat resistant resin having heat resistance in a temperature range of 90° C. to 200° C. and a positive thermoacoustic characteristics in which the ultrasonic transmittance increases as the temperature rises in such a temperature range. (5) A flowmeter sensor comprising an ultrasonic transducer that generates ultrasonic waves, a pipe through which a fluid flows, and an acoustic prism having a bottom surface that is arranged in contact with the outer peripheral surface of the pipe and a front-side inclination face that supports the ultrasonic transducer, and propagates ultrasonic waves from the ultrasonic transducer toward the fluid in the pipe, wherein the acoustic prism is made of a heat-resistant resin having heat resistance in a temperature range of 60° C. to 200° C. and a positive thermoacoustic characteristic in which the ultrasonic transmittance increases as the temperature rises in such a temperature range.
DESCRIPTION OF REFERENCE NUMERALS
(37) **1**: Pipe **11**: Flowmeter sensor **61**, **61**A, **61**B, **61**C, **61**D: Acoustic prism **63**: Front side inclination face **64**: Ultrasonic transducer **65**: Bottom surface **81**: Coupling material layer B**1**: Ultrasonic wave propagation path **62***a*: Hollow portion

## Claims

1. A flowmeter sensor comprising an ultrasonic transducer that generates ultrasonic waves, a pipe through which a fluid flows, and an acoustic prism having a bottom surface that is arranged in contact with the outer peripheral surface of the pipe and a front-side inclination face that supports the ultrasonic transducer, and propagates ultrasonic waves from the ultrasonic transducer toward the fluid in the pipe, wherein the pipe is made of a first heat-resistant resin having heat resistance in a temperature range of 90° C. to 200° C. and negative thermoacoustic characteristics in which the ultrasonic transmittance decreases as the temperature rises in such a temperature range, and the acoustic prism is made of a second heat-resistant resin having heat resistance in a temperature range of 90° C. to 200° C. and positive thermoacoustic characteristics in which the ultrasonic transmittance increases as the temperature rises in such a temperature range.
2. A flowmeter sensor according to claim 1, wherein an ultrasonic wave propagation path is formed by the pipe and the acoustic prism; thereof, the length occupied by the acoustic prism in the entire length of the ultrasonic wave propagation path is greater than that occupied by the pipe in the entire length of the ultrasonic wave propagation path.
3. A flowmeter sensor according to claim 2, wherein the second heat-resistant resin is polyether sulfone, and the first heat-resistant resin is a fluororesin that has a higher heat resistance than the second heat-resistant resin.
4. A flowmeter sensor according to claim 1, wherein a coupling material layer is further provided in contact with the outer peripheral surface of the pipe and the bottom surface of the acoustic prism, said coupling material layer is made of a heat-resistant material having a heat resistance in the temperature range of 90° C. to 200° C.
5. A flowmeter sensor according to claim 4, wherein the heat-resistant material has negative thermoacoustic characteristics in which the ultrasonic wave transmittance decreases as the temperature rises in the temperature range of 90° C. to 200° C.
6. A flowmeter sensor according to claim 5, wherein an ultrasonic wave propagation path is formed by the pipe, the coupling material layer, and the acoustic prism, thereof the length occupied by the acoustic prism over the entire length of the ultrasonic wave propagation path is greater than the sum of the length occupied by the pipe and the length occupied by the coupling material layer in the entire length of the ultrasonic propagation path.
7. A flowmeter sensor according to claim 6, wherein the second heat-resistant resin is polyether sulfone, the first heat-resistant resin is a fluororesin having a higher heat resistance than the second heat-resistant resin, and the heat-resistant material is a fluororubber having a higher heat resistance than the second heat-resistant resin.
8. A flowmeter sensor according to claim 1, wherein an intermediate portion connecting the front-side inclination face and the bottom surface of the acoustic prism has a hollow portion formed on both sides.
9. A flowmeter sensor according to claim 1, wherein an intermediate portion connecting the front-side inclination face and the bottom surface in the acoustic prism has a width that becomes narrower toward the bottom surface side.
10. A flowmeter sensor according to claim 1, wherein the ultrasonic transducer is made of a porous body of alkali niobate-based piezoelectric ceramics.