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(54) **BOLT-TIGHTENING LANGEVIN-TYPE TRANSDUCER, ULTRASONIC MEASURING DEVICE**

(57) This invention is to provide a bolt-tightening Langevin-type transducer and an ultrasonic measuring-device, both made of a lead-free piezoelectric material, which can realize a performance equal to or greater than that of a transducer made of a leaded piezoelectric material. The Langevin-type transducer 11 of this invention has a structure in which a drive-unit 31 is sandwiched between a front mass 21 and a rear mass 22. The drive-unit 31 is formed by laminating together a plurality of piezoelectric elements 32, made of a lead-free material, and electrode plates 33. The front mass 21 and the rear mass 22 are fastened together by a fastening bolt 25 inserted into a hole 34 penetrating the drive-unit 31. The drive-unit 31 includes four pieces or more of piezoelectric elements 32 formed of an alkali niobate-based ceramic-piezoelectric material. The front mass 21 is formed of a first-metal material. The rear mass 22 is formed of a second-metal material having a specific gravity greater than that of the first-metal material.

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Description

Technical Field

5 **[0001]** This invention relates to a bolt-tightening Langevin-type transducer and to an ultrasonic-measuring device using the same.

Technical Background

10 **[0002]** Conventionally, a bolt-tightening Langevin-type transducer 51, as shown in FIG. 6A, is well known. Of this bolt-tightening Langevin-type transducer 51, a drive-unit 56 that is made by laminating two piezoelectric elements 54 and two electrode plates 55 together is sandwiched between a front mass 52 and a rear mass 53. A fastening bolt (not shown in the drawings) is inserted into the hole penetrating the drive-unit 56. In fastening such fastening bolt, the front mass 52 and the rear mass 53 are thus fastened, and the respective members are integrated. In addition, a thing that is similar
15 in structure to such transducer 51 is disclosed in e.g. Patent Document 1 or the like.

[0003] Of the conventional bolt-tightening Langevin-type transducer 51, the front mass 52 and the rear mass 53 are formed generally using a metal material such as aluminum or the like. Generally, the piezoelectric element 54 is formed using a ceramic-piezoelectric material containing lead such as lead zirconate titanate (PZT). In recent years, from the viewpoint of enhancing the environment, there has been increasing demand for a piezoelectric element 54 using a lead-free ceramic-piezoelectric material.
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Prior Arts

Patent Documents

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[0004] Patent Document 1: Unexamined Japanese Patent Application No.: H8 (1996)-89893

Summary of the invention

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Problems to be resolved by the invention

[0005] Though lead-free ceramic-piezoelectric materials are preferable in terms of having less harmful effect on the environment, such materials are inferior in piezoelectric properties as compared to leaded ceramic-piezoelectric materials such as PZT. Therefore, even if the transducer 51 having the above structure is made using the piezoelectric element
35 54 formed of a lead-free ceramic-piezoelectric material, it is difficult to realize the same performance as that of the conventional transducer made by using the piezoelectric element 54 that is formed of PZT. Therefore, until now some measure for realizing such performance has been desired.

[0006] The bolt-tightening Langevin-type transducer 51 has relatively much power and is usually employed for machining applications. However, when such performance is realized, it is also desired that it be used for measuring purposes.
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[0007] This invention has been achieved in light of the above-referenced problems, the purpose of which is to provide a bolt-tightening Langevin-type transducer and an ultrasonic measuring device that can realize a performance equal to or better than that of a transducer using a leaded-piezoelectric material, despite this invention using a lead-free piezoelectric material.
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Means of solving the problems

[0008] In view of the above-mentioned problems, the inventors of this invention have done intensive research. Based on the prediction that from among the many lead-free ceramic-piezoelectric materials the alkali niobate-based ceramic-piezoelectric material is suitable, they configured the drive-unit by using two pieces of piezoelectric elements formed by such alkaline niobate-based ceramic-piezoelectric material in the conventional manner. However, the desired performance as expected could not be achieved. Then, after more trial and error, the inventors of this invention learned that the desired suitable performance can be achieved by increasing the number of piezoelectric elements by greater than two pieces and by making the rear mass heavier than the front mass. As a result, they finally developed the invention as described below.
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[0009] To solve the above-mentioned problems, the first aspect of this invention refers to a bolt-tightening Langevin-type transducer having a structure in which a drive-unit, formed by laminating together a plurality of piezoelectric elements, made of a lead-free material, and electrode plates, is sandwiched between a front mass and a rear mass, and therein

the front mass and the rear mass are fastened together by a fastening bolt inserted into a hole penetrating the drive-unit, characterized in that the drive-unit includes four or more piezoelectric elements formed by using an alkali niobate-based ceramic-piezoelectric material, and therein the front mass is formed by using a first-metal material, and the rear mass is formed by using a second-metal material having a specific gravity greater than that of the first-metal material.

5 **[0010]** Therefore, the first aspect of this invention allows for reducing the weight of the front mass by forming the front mass using a first-metal material having a relatively low specific gravity and by forming the rear mass using a second-metal material having a relatively high specific gravity, so that the amplitude on the front-mass side can be increased. Among lead-free ceramic-piezoelectric materials, alkali niobate-base ceramic-piezoelectric materials have relatively excellent piezoelectric characteristics. The drive-unit that is configured by including four or more piezoelectric elements that are formed using such lead-free ceramic-piezoelectric materials can generate greater oscillation energy compared to the conventional structure. As a result, even though the four or more piezoelectric elements are formed using a lead-free piezoelectric material, it is possible to realize a performance equivalent to or greater than that using a leaded piezoelectric material. In addition, according to this invention, the four or more piezoelectric elements are formed using an alkali niobate-based ceramic-piezoelectric material that is better for the environment and that makes it easier to reduce the weight of the whole apparatus.

10 **[0011]** The second aspect of this invention refers to a bolt-tightening Langevin-type transducer according to the first aspect of this invention, characterized in that the piezoelectric element is formed using a sodium-potassium niobate-based ceramic-piezoelectric material.

15 **[0012]** Therefore, the second aspect of this invention allows for making a drive-unit using sodium-potassium niobate-based (KNN-based) ceramics having particularly preferable piezoelectric characteristics from among other alkali niobate-based ceramics, thus making it possible reliably to generate greater oscillation energy.

20 **[0013]** The third aspect of this invention refers to a bolt-tightening Langevin-type transducer according to the first or second aspect of this invention, characterized in that the specific gravity of the second-metal material is twice or more than that of the first-metal material.

25 **[0014]** Therefore, the third aspect of this invention allows for lightening the front mass without changing so much the size and shape of the front mass and of the rear mass, since the difference in specific gravity between the first-metal material and the second-metal material is sufficiently great, thus making it possible to increase the amplitude on the front-mass side.

30 **[0015]** The fourth aspect of this invention refers to a bolt-tightening Langevin-type transducer according to the third aspect of this invention, characterized in that the specific gravity of the first-metal material is 2.5 or more and 3.5 or less, and that the specific gravity of the second-metal material is 7.0 or more and 9.0 or less.

35 **[0016]** Therefore, the fourth aspect of this invention allows for relatively easily selecting materials suitable for the first-metal material and for the second-metal material, respectively, within the above specific gravity range.

40 **[0017]** The fifth aspect of this invention refers to a bolt-tightening Langevin-type transducer according to any one of the first through fourth aspects of this invention, characterized in that the total length of the transducer corresponds to half of the wavelength of the resonance frequency, and that the thickness of the drive-unit is less than one third of the total length of the transducer, and that the thickness of the front mass is more than one third of the total length of the transducer.

45 **[0018]** Therefore, the fifth aspect of this invention allows for easily arranging the whole drive-unit in the vicinity of the oscillation node, since, in respect to the case of which the total length of the transducer corresponds to half of the wavelength of the resonance frequency, the thickness of the drive-unit is subject to less than one third of the total length of the transducer. Therefore, the amplitude in the drive-unit can be suppressed, and peeling or the like can hardly occur at the joint interface between the piezoelectric element and the electrode plate. Further, the electric field is increased as the thickness of each piezoelectric element constituting the drive-unit is reduced. As such, the oscillatory displacement is increased, and then the transmitted acoustic pressure is also increased. Also, the ratio of the thickness of the front mass to the total length of the transducer is increased, which makes it easier to keep oscillation even when the rear mass is relatively heavy, thus making it possible reliably to increase the amplitude more on the front-mass side.

50 **[0019]** The sixth aspect of this invention refers to a bolt-tightening Langevin-type transducer having a structure in which a drive-unit, formed by laminating together a plurality of piezoelectric elements, made of a lead-free material, and electrode plates, is sandwiched between a front mass and a rear mass therein, and that the front mass and the rear mass are fastened together by a fastening bolt inserted into a hole penetrating the drive-unit, characterized in that the drive-unit includes four or more piezoelectric elements formed by using an alkali niobate-based ceramic-piezoelectric material, therein the front mass and the rear mass are formed by using a metal material of equal specific gravity, as well as the weight of the rear mass is greater than that of the front mass.

55 **[0020]** Therefore, the sixth aspect of this invention allows for relatively lightening the front mass compared to the rear mass, thus making it possible to increase the amplitude on the front-mass side. Among lead-free ceramic-piezoelectric materials, alkaline niobate-based ceramic-piezoelectric materials are relatively excellent in piezoelectric property, and since the drive-unit comprises four or more pieces of piezoelectric elements and is formed using such material, greater

oscillation energy can be generated compared to the conventional structure, thus making it possible to realize a performance equal to or greater than that using a leaded piezoelectric material, even though such piezoelectric element is formed by using a lead-free piezoelectric material. In addition, according to this invention, the piezoelectric element is formed using an alkali niobate-based ceramic-piezoelectric material, which is less harmful to the environment, and which thus makes it easier to reduce the weight of the whole apparatus.

[0021] The seventh aspect of this invention refers to an ultrasonic measuring device for measuring a physical quantity by transmitting and receiving ultrasonic waves, characterized in that the ultrasonic measuring device comprises one or more bolt-tightening Langevin-type transducers according to any one of the first through sixth aspects of this invention.

[0022] The eighth aspect of this invention refers to an ultrasonic measuring device according to the seventh aspect of this invention, characterized in that the ultrasonic measuring device is a fish-detection sensor having a structure of which a plurality of the bolt-tightening Langevin-type transducers are rubber-molded in the same direction.

Effect of the invention

[0023] As described above in detail, the first through eighth aspects of this invention can provide a bolt-tightening Langevin-type transducer and an ultrasonic measuring device that realizes a performance equal to or greater than that using a leaded piezoelectric material, even though such piezoelectric element is formed by using a lead-free piezoelectric material.

Brief description of the drawings

[0024]

FIG. 1 is the front view of the bolt-tightening Langevin-type transducer as the embodiment of this invention.

FIG. 2 is the top view of the bolt-tightening Langevin-type transducer as the embodiment of this invention.

FIG. 3 is the cross-sectional view between the A-A line of FIG. 2.

FIG. 4 is the schematic longitudinal cross-sectional view of a fish-detection sensor configured using the bolt-tightening Langevin-type transducer as the embodiment of this invention.

FIG. 5 is the schematic cross-sectional view between the B-B line of FIG. 4.

FIG. 6 (a) is the schematic view of the bolt-tightening Langevin-type transducer as a comparison example to the conventional embodiment. FIG. 6(b) is the schematic view of the bolt-tightening Langevin-type transducer as a second comparison example, and FIG. 6(c) is the bolt-tightening Langevin-type transducer as the embodiment of this invention.

FIG. 7 is the graph comparing the relationship between the input voltage and the radiation-surface amplitude.

FIG. 8 is the graph comparing the transmitted acoustic-pressure to the wave-receiving sensitivity.

FIG. 9 is the graph comparing the directivity characteristics.

Modes for carrying out the invention.

[0025] Hereinafter, a bolt-tightening Langevin-type transducer 11 and a fish-detection sensor 41 as the embodiment of this invention are described in detail in reference to FIGS. 1 to FIG. 9.

[0026] As shown in FIGS. 1 to 3, the bolt-tightening Langevin-type transducer 11 as the embodiment of this invention consists of a front mass 21, a rear mass 22, a drive-unit 31, and a clamping bolt 25.

[0027] The front mass 21 (front plate) is arranged on the front-end side of the bolt-tightening Langevin-type transducer 11 and emits ultrasonic waves from the front surface 26 thereof. The rear mass 22 (backing plate) is arranged on the rear-end side of the bolt-tightening Langevin-type transducer 11. Of the embodiment of this invention, the front mass 21 is formed in a 25 mm squared rectangular shape, while the rear mass 22 is formed in a 25 mm diameter circular shape (see FIG. 2).

[0028] The drive-unit 31 is formed by laminating together a plurality of piezoelectric elements 32 and electrode plates 33 (four pieces are laminated in this embodiment) which are then sandwiched between the front mass 21 and the rear

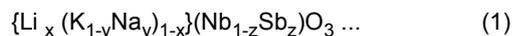
mass 22. Since the piezoelectric element 32 is annular-shaped, and the electrode plate 33 is substantially annular-shaped with a tab portion in part, the driving portion 31 has a bolt-insertion hole 34 penetrating through its center. Each piezoelectric element 32 is polarized in the thickness direction, and each polarized direction is indicated by an arrow, as shown in FIG. 4. The front mass 21 and the rear mass 22 are formed with female bolt holes 24 and 23, respectively, and are formed coaxially with the central axis C1 of the transducer 11. The female bolt hole 23 on the rear mass 22 is a through hole, whereas the female bolt hole 24 on the front mass 21 is a non-through hole that does not penetrate the front surface 26. A fastening bolt 25 with an external thread formed on the outer-peripheral surface is inserted from the rear mass 22, and the tip of the fastening bolt 25 reaches the female bolt hole 24 on the front mass 21 via the female bolt hole 23 and the bolt insertion hole 34. The fastening bolt 25 is inserted into the female bolt holes 23 and 24. Fastening the fastening bolt 25 makes the front mass 21, the drive-unit 31 and the rear mass 22 firmly joined together.

[0029] Of the bolt-tightening Langevin-type transducer 11 as the embodiment of this invention, the front mass 21 is formed using a first-metal material having a specific gravity of 2.5 or more and 3.5 or less, and the rear mass 22 is formed using the second-metal material of a specific gravity greater than that of the first-metal material, that is, having a specific gravity of 7.0 or more and of 9.0 or less. Specifically, the front mass 21 is formed using aluminum (specific gravity 2.7) as the first-metal material, and the rear mass 22 is formed using stainless steel such as SUS304 or the like (specific gravity: around 7.70 to 8.00) as the second-metal material. That is, the specific gravity of the metal material used for the rear mass 22 is about 2.9 times as much as the specific gravity of the metal material used for the front mass 21. In addition, stainless steel is arbitrary, though here it is used for the metal material that forms the fastening bolt 25.

[0030] Of the bolt-tightening Langevin-type transducer 11 as the embodiment of this invention, the piezoelectric elements 32 that configure the drive-unit 31 are all formed using a lead-free ceramic-piezoelectric material, specifically, an alkali niobate-based ceramic-piezoelectric material.

[0031] Preferable examples of such alkali niobate-based ceramic-piezoelectric materials include a potassium-sodium niobate-based (KNN-based) ceramic-piezoelectric material or the like having a perovskite structure that is a solid solution of potassium niobate and sodium niobate. A KNN-based ceramic-piezoelectric material means a material containing at least K (potassium), Na (sodium) and Nb (niobium) as the main metallic composition. Such composition contains few or not any toxic and harmful elements, as well as not containing any Pb (lead). Such a KNN-based ceramic-piezoelectric material may contain an alkali metal such as Li (lithium) or the like, as well as K (potassium) and Na (sodium). In addition, such material may contain Ca (an alkaline earth metal such as calcium), Sr (strontium), Ba (barium), Ta (tantalum) and Sb (antimony) or the like, as well as Nb (niobium). Also, such a KNN-based ceramic-piezoelectric material may contain a small amount of Bi (bismuth), Fe (iron), Al (aluminum), Mn (manganese), Co (cobalt) and Ni (nickel) or the like.

[0032] Particularly, regarding the embodiment of this invention, the piezoelectric element 32 is formed of a KNN-based ceramic-piezoelectric material, as represented by the following composition formula (1), which has a small amount of Bi (bismuth) and Fe (iron) as added metal elements.



[0033] Of such composition formula (1), when the added amount of Bi (mol ratio) is v , and the added amount of Fe (mol ratio) is w , the composition shall be satisfied with a range of $0.03 \leq x \leq 0.045$, $0.5 \leq y \leq 0.58$, $0.03 \leq z \leq 0.045$ and $0.006 \leq v < w \leq 0.010$. In using a KNN-based ceramic-piezoelectric material that has such a satisfactory composition range, then it will be easier to obtain good piezoelectric characteristics (e.g. the piezoelectric constant d_{33} is 250_pC/N or more; the Curie temperature T_c is 330 degrees Celsius or more), and to obtain good electrical characteristics (e.g. the electromechanical coupling coefficient K_p in the radial direction is 0.44 or more; the relative dielectric constant $\epsilon_{33}^T / \epsilon_0$ is 1,390 or more; and the dielectric loss $\tan \delta$ is 0.03 or less). Furthermore, when the KNN-based ceramic-piezoelectric material is satisfactorily within the composition range of $0.007 \leq v < w \leq 0.009$, then it will be possible easily to obtain better characteristics such as the piezoelectric constant d_{33} of 270_pC/N or more; the Curie temperature T_c of 340 degrees Celsius or more; the radial electromechanical coupling coefficient K_p of 0.47 or more; the relative dielectric constant $\epsilon_{33}^T / \epsilon_0$ of 1,450 or more, and the dielectric loss $\tan \delta$ of 0.25 or less.

[0034] As shown in FIG. 1, the bolt-tightening Langevin-type transducer 11 as the embodiment of this invention is formed such that the resonance frequency is 50kHz, and the total length L1 of the transducer is approximately 42mm. In other words, the total length L1 of the transducer corresponds to half of the wavelength ($\lambda/2$) of the resonance frequency.

[0035] The thickness T3 of the front mass 21 preferably is more than one third of the total length L1 of the transducer, more preferably 34% to 44% of the total length L1 of the transducer. In the case of the embodiment of this invention, it is approximately 16mm (or approximately 38% of the total length L1).

[0036] The thickness T1 of the rear mass 22 is preferably about 1/3 of the total length L1 of the transducer, more preferably 30% to 40% of the total length L1 of the transducer. Of such thickness T1 of the rear mass 22, the thickness T1 should be about 15mm (or approximately 36% of the total length L1 of the transducer). Also, it is preferable that the thickness T1 of the rear mass 22 be slightly less than the thickness T3 of the front mass 21, as described above.

[0037] Furthermore, the thickness T2 of the drive-unit 31 that is the sum of the thicknesses of the four pieces of the

piezoelectric elements 32 and of the four pieces of the electrode plates 33 is preferably one third or less than the total length L1 of the transducer. More preferably, it is 21% to 31% of the total length L1 of the transducer. In this case, it should be about 11 mm (or approximately 26% of the total length L1 of the transducer). Incidentally, the thickness of each piezoelectric element 32 should be about 2.5 mm, and the thickness of each electrode plate 33 should be much thinner than each piezoelectric element 32, about 0.2 mm.

[0038] As shown in FIG. 1, the bolt-tightening Langevin-type transducer 11 as the embodiment of this invention is designed such that the ultrasonic-oscillation node F1 is focused on the central part of the drive-unit 31 that is the intermediate point in the direction of the length of the transducer, more specifically on the interface between the piezoelectric element 32 and the electrode plate 33 located on the second layer and on the interface between the piezoelectric element 32 and the electrode plate 33 located on the third layer. In addition, the bolt-tightening Langevin-type transducer 11 is designed such that the abdomen H1 of the ultrasonic oscillation is focused on both ends of the transducer (on each end-face of the front mass 21 and rear mass 22).

[0039] FIGS. 4 and 5 show a fish-detection sensor 41 configured using the bolt-tightening Langevin-type transducer 11 as the embodiment of this invention. The fish-detection sensor 41 has a structure in which a plurality of bolt-tightening Langevin-type transducers 11 are rubber-molded in the same direction. More specifically the container (rubber-mold part) of the fish-detection sensor 41 comprises a main-container body 42 and a lid part 43. The bottom part 45 of the container body 42 also serves as an acoustic-matching layer, and four pieces of the bolt-tightening Langevin-type transducers 11 are firmly joined to the bottom part 45 such that the front mass 21 is directed downward. An electric wire (not shown in the drawing) is electrically connected to the tab portion of the electrode plate 33 in each bolt-tightening Langevin-type transducer 11. These electric wires are drawn out of the sensor via the cable 44 and are electrically connected to a drive-control unit that has an oscillator and the like and which are connected to a power unit (both not shown in the drawing). The fish-detection sensor 41 having such a structure makes the four pieces of bolt-tightening Langevin transducers 11 simultaneously to drive and start oscillating based on the drive-signal being emitted from the drive-control unit. Then, ultrasonic waves that are generated by the bolt-tightening Langevin-type transducers 11 are transmitted to the bottom part 45 of the container body 42 and then are radiated from the bottom surface of the container to the outside of the container. Furthermore, the reflected wave of the ultrasonic wave, radiated earlier, is transmitted to each bolt-tightening Langevin-type transducer 11 via the bottom part 45 of the container body 42 and is transmitted to the drive-control unit as a detection signal.

[0040] Hereinafter, more specific embodiments of this invention will be described.

Embodiment

[0041] As embodiments of this invention, the following three types of bolt-tightening Langevin-type transducers have been produced. FIG. 6(C) basically shows the bolt-tightening Langevin-type transducer 11 of the embodiment as described above, having a structure in which the drive-unit 31, formed by laminating together each of the four piezoelectric elements 32 of the KNN-based ceramic-piezoelectric material, represented as the above composition formula (1), and of each of the four electrode plates 33, of which drive-unit 31 is then sandwiched between the aluminum front mass 21 and the stainless-steel rear mass 22. FIGS. 6 (a) to 6 (c) also show with arrows the direction of polarization.

[0042] The method for manufacturing the piezoelectric element 32 to be used is described here in detail. Firstly, a base powder (purity 99% or more) of K_2CO_3 , Na_2CO_3 , Li_2CO_3 , Nb_2O_5 , Sb_2O_3 , Bi_2O_3 and Fe_2O_3 was prepared. Then, such base powder containing each metal element was weighed to satisfy the composition as represented in the above composition formula (1). Then, such base powder was mixed in alcohol for 24 hours by a ball mill, thus obtaining a mixed slurry. Although the type of base powder (compound) containing each metal element is not specifically limited, an oxide, a carbonate or the like of each metal element can be used. Next, the obtained mixed slurry was dried, calcined at 900 degrees Celsius for 3 hours and then ground by a ball mill for 24 hours. Further, an aqueous solution of polyvinyl alcohol was added to the base powder as a binder to be granulated. Then, such granulated powder was pressure-molded into an annular shape of 24 mm in diameter and into a thickness of about 2.5 mm at a pressure of 200 MPa. Then, such compact was fired at 1,000 to 1,200 degrees Celsius for two and a half hours to be a calcined body. The firing temperature at this time was selected so that such calcined body would, at a temperature of between 1,000 to 1,200 degrees Celsius, attain maximum density. After this, a double-sided polishing, a polarization processing and the like were performed to obtain a piezoelectric element 32 formed of a KNN-based ceramic piezoelectric material.

[0043] FIG. 6(b) shows a bolt-tightening Langevin-type transducer 11A as the Comparative Example 2, which is common to the embodiment of this invention at the point that the drive-unit 31, formed by laminating together the piezoelectric element 32 made of a KNN-based ceramic-piezoelectric material, as represented in the above composition formula (1), and the electrode plate 33, which drive-unit 31 is then sandwiched between the front mass 21 and the rear mass 22. However, it is different from the embodiment of this invention in that both the front mass 21 and rear mass 22 are made of aluminum, and that two of each of the piezoelectric elements 32 and electrode plates 33 are used to form the drive-unit 31, and that the piezoelectric element 32 is thick.

[0044] FIG. 6(a) shows a bolt-tightening Langevin-type transducer 51 as Comparative Example 1 (conventional example), which is common to the embodiment of this invention at the point that the drive-unit 56, formed by laminating together the piezoelectric element 54 made of a ceramic-piezoelectric material, and the electrode plate 55, which drive-unit 56 is then sandwiched between the front mass 52 and the rear mass 53. However, it is different from the embodiment of this invention in that both the front mass 52 and rear mass 53 are made of aluminum, and that two of each of the piezoelectric elements 54 and electrode plates 55 are used to form the drive-unit 56, and that the piezoelectric element 54 is thick and formed of PZT (i.e. a leaded ceramic-piezoelectric material).

[0045] To compare the performance of the embodiment, of Comparative Example 1 and Comparative Example 2, the relationship between the input power and the radiation-surface amplitude was investigated. The result is shown in the graph of FIG. 7. In this graph, the data curve of the embodiment is represented as the connecting points marked with \blacklozenge ; the data curve of Comparative Example 1 is represented as the connecting points marked with \blacksquare ; and the data curve of Comparative Example 2 is represented as the connecting points marked with \bullet .

[0046] In the case of Comparative Example 1, it was confirmed that there was a tendency for the radiation-surface amplitude to increase linearly when the input power is within the range of about 10W or less, but that once the input power is within a range exceeding about 10W, then such linearity breaks up, and the waveform is distorted. Therefore, it was suggested that the bolt-tightening Langevin-type transducer 51 as Comparative Example 1 cannot stably be used within a range exceeding about 10W.

[0047] As shown in the graph of FIG. 7, in the case of Comparative Example 2, a curve is drawn in the position lower than that of Comparative Example 1, and that the radiation-surface amplitude, with respect to the input voltage, is much less. Also, it was recognized that the radiation-surface amplitude tended to increase linearly when the input power was about 5W or less, but that once the input power is within a range exceeding about 5W, then such linearity breaks up, and the waveform is distorted. Therefore, it was confirmed that the bolt-tightening Langevin-type transducer 11A as Comparative Example 2 has a narrower range of power that can be stably used than that range of power of Comparative Example 1. From the above, Comparative Example 2 is preferable in that it has less harmful effect on the environment, but that it is impossible to generate a greater amount of oscillation energy on the front mass 21 compared to that of Comparative Example 1 configured using PZT. Therefore, it was concluded that Comparative Example 2 could not achieve the same piezoelectric performance as can be seen in Comparative Example 1.

[0048] As shown in the graph of FIG. 7, contrarily, in the case of the embodiment of this invention, a curve is drawn at a position higher than that of Comparative Example 1, and that the radiation-surface amplitude, with respect to the input voltage, is totally increased. Also, it was recognized that the radiation-surface amplitude tended to increase linearly until the input power reached about 15W. Therefore, it was confirmed that the bolt-tightening Langevin-type transducer 11 as the embodiment of this invention has a wider range of power that can be stably used compared to that of Comparative Example 1. From the above, it has been confirmed that the embodiment of this invention can generate greater oscillation energy on the front mass 21 compared to that amount of such generated energy of Comparative Example 1 configured using PZT, as well as that such generated energy has less harmful effect on the environment. Therefore, it was concluded that the embodiment of this invention achieves a superior piezoelectric performance to that of the embodiment of Comparative Example 1.

[0049] Next, a fish-detection sensor 41, as shown in FIGS. 4 and 5, was produced using both the bolt-tightening Langevin-type transducer 11 as the embodiment of this invention and the bolt-tightening Langevin-type transducer 51 of Comparative Example 1, thus in using them together the performance of each was compared. The upper graph of FIG. 8 shows the comparison of the transmitted acoustic pressures of both transducers, while the lower graph of FIG. 8 shows the comparison of the wave-receiving sensitivities of both transducers. In either case, the horizontal axis represents frequency, and the vertical axis represents acoustic pressure (sensitivity). As shown in FIG. 8, the data curve of the embodiment is represented as the connecting points marked with \blacklozenge , and the data curve of Comparative Example 1 is represented as the connecting points marked with \blacksquare . According to the comparison, above, it was concluded that the embodiment has almost the same transmitting/receiving sensitivity as Comparative Example 1. Also, the upper graph of FIG. 9 shows the comparison of the directivity characteristic of the embodiment of this invention, while the lower graph of FIG. 9 shows the comparison of the directivity characteristic of Comparative Example 1. This shows that the half-full angle of Comparative Example 1 was 48 degrees, while the half-full angle of the embodiment was 30 degrees. Therefore, it has been recognized that the embodiment of this invention allows for realizing a narrower directivity angle.

[0050] Also, the embodiment of this invention realizes the following effects.

- (1) Of the bolt-tightening Langevin-type transducer 11 as the embodiment of this invention, the front mass 21 is formed using aluminum (first-metal material) having a relatively low specific gravity, and the rear mass 22 is formed using stainless steel (second-metal material) having a relatively high specific gravity). As such, the front mass 21 can be lightened, and the amplitude on the front mass 21 can be increased. Among lead-free ceramic-piezoelectric materials, alkaline niobate-based ceramic-piezoelectric materials have relatively excellent piezoelectric property. As the drive part 31 was comprised including four pieces or more of piezoelectric elements 32 formed using such

a material, a greater oscillation energy can be generated compared to the conventional structure. As a result, even though the piezoelectric element 32 is formed of a lead-free piezoelectric material, it is possible to realize a performance equal to or greater than that of the PZT. Furthermore, according to the embodiment of this invention, since the piezoelectric element 32 is formed using an alkali niobate-based ceramic-piezoelectric material, there is less harm to the environment, and it is easier to lighten the weight of the entire apparatus.

(2) Of the embodiment of this invention, the drive-unit 31 is configured by using a KNN-based ceramic of a particular composition, which has especially preferable piezoelectric characteristics among alkali niobate-based ceramics. Therefore, it is possible reliably to generate greater oscillation energy. Eventually, it is relatively easy to realize a performance equal to or better than that of PZT.

(3) Of the embodiment of this invention, the difference in specific gravity between the aluminum that is the first-metal material and the stainless steel that is the second-metal material is twice or more, and such a difference is sufficiently great. For this reason, the front mass 21 can be lightened without significantly changing the dimensions and shapes of the front mass 21 and of the rear mass 22, thus making it possible to increase the amplitude on the front mass 21.

(4) Of the embodiment of this invention, the thickness T2 of the drive-unit 31 is subject to less than one-third of the total length L1 of the transducer when the total length L1 of such transducer corresponds to a length of half of the wavelength $\lambda/2$ of the resonance frequency, thus making it easy to arrange the whole drive-unit 31 in the vicinity of the oscillation node F1. Therefore, the amplitude in the drive-unit 31 can be suppressed, and peeling or the like hardly occurs at the joint interface between the piezoelectric element 32 and the electrode plate 33. Further, the electric field is increased as the thickness of each piezoelectric element 32 constituting the drive-unit 31 is reduced. As such, the oscillatory displacement is increased, and then the transmitted acoustic pressure is also increased. Also, the ratio of the thickness of the front mass 21 to the total length L1 of the transducer is increased, which makes it easier to keep oscillation, even when the rear mass 22 is relatively heavy, thus making it possible reliably to increase the amplitude more on the front-mass 21.

(5) Since the KNN-based ceramic-piezoelectric material used in the embodiment of this invention is excellent in high-voltage resistance compared to that of PZT, even if the piezoelectric element 32 is thin and the electric field at the time of driving is about twice as much, then deterioration of the piezoelectric property can be suppressed. Therefore, it becomes easy to form the thin piezoelectric element 32 by using the KNN-based ceramic-piezoelectric material, and the drive-unit 31, with its overall thickness reduced, can be produced by laminating together a plurality of piezoelectric elements 32.

[0051] Each embodiment of this invention can be modified, as follows.

- Of the embodiment as described above, the piezoelectric element 32 is formed by using a KNN-based ceramic-piezoelectric material as the alkali niobate-based ceramic-piezoelectric material. However, it is certainly possible to use an alkali niobate-based ceramic-piezoelectric material other than the KNN-based ceramic-piezoelectric material.
- Of the embodiment as described above, the drive-unit 31, including four pieces of piezoelectric elements 32, is exemplified. However, it is also possible to configure the drive-unit 31 by including more than four pieces (e.g., six or eight pieces) of piezoelectric elements 32.
- Of the embodiment as described above, the bolt-tightening Langevin-type transducer 11, whose resonance frequency is 50kHz and whose total length L1 of the transducer corresponds to half of the wavelength $\lambda/2$ of the resonance frequency, is exemplified. However, the resonance is not limited to 50kHz and may be of any arbitrary frequency, e.g. in the range of 25kHz through 50kHz. The total length L1 of the transducer is not limited to the length corresponding to half of the wavelength $\lambda/2$ of the resonance frequency and may be equivalent e.g. to the length of the wavelength λ .
- Of the embodiment as described above, the front mass 21 is formed using aluminum that is the first-metal material, and the rear mass 22 is formed using stainless steel that is the second-metal material having a specific gravity greater than that of the first-metal material. However, it is not limited to this. For example, a metal material other than aluminum, e.g., an aluminum alloy such as duralumin (specific gravity: 2.80) or the like, or magnesium (specific gravity: 1.74) or a magnesium alloy, or titanium (specific gravity: 4.51) or a titanium alloy (6-4) (specific gravity: 4.43) or the like may be used as the first-metal material to form the front mass 21. It is also possible to form the rear mass 22 using as the second-metal material for example a metal other than stainless steel, e.g., copper (specific gravity:

8.96) or a copper alloy such as brass (specific gravity: 8.50 to 8.70), or a steel material such as carbon steel and nickel steel (specific gravity: 7.70 to 9.00) or the like, or nickel (specific gravity: 8.90) or a nickel alloy (specific gravity: 8.50-9.30), or chromium (specific gravity: 7.19) or a chromium alloy, or cobalt (specific gravity: 8.85) or a cobalt alloy or the like.

- 5 • Of the embodiment as described above, the front mass 21 has a rectangular cross-section, and the rear mass 22 has a circular cross-section. However, it is not limited to this. For example, both the front mass 21 and rear mass 22 may have a rectangular cross-section, and both the front mass 21 and rear mass 22 may have a circular cross-section. Furthermore, at least one of either the front mass 21 or rear mass 22 may have a polygonal cross-section and not a rectangular cross-section (e.g., a hexagonal cross-section).
- 10 • Of the embodiment as described above, the front mass 21 is longer (thicker) than the rear mass 22, but this magnitude relationship may be reversed. Also, it is possible to make both lengths (thicknesses) equal.
- 15 • Of the embodiment as described above, the front mass 21 is formed using the first-metal material, and the rear mass 22 is formed using the second-metal material having a specific gravity greater than that of the first-metal material. However, it is still possible to form the front mass 21 and the rear mass 22 by using a metal material of equal specific gravity, if the specific gravity of the rear mass 22 should be greater than that of the front mass 21. Also, as the above-mentioned "metal-material having equal specific gravity," it is possible to select same types of metal-material having the same specific gravity or to select different types of metal-material having the same specific gravity.
- 20 • Of the embodiment as described above, the fish-detector sensor 41 is configured using the bolt-tightening Langevin-type transducer 11. However, an ultrasonic measuring device other than the fish-detector sensor 41 (e.g., an aerial ultrasonic sensor, an ultrasonic level-meter, an ultrasonic flow-meter, an ultrasonic densitometer, an ultrasonic bubble-detection sensor, an ultrasonic knocking-sensor or the like) can be configured using such a transducer 11.
- 25

Description of the reference numerals

30 [0052]

- 11: Bolt-tightening Langevin-type transducer
- 21: Front mass
- 22: Rear mass
- 35 25: Fastening bolt
- 31: Drive-unit
- 32: Piezoelectric element
- 33: Electrode plate
- 34: Hole
- 40 41: Fish-detection sensor
- L1: Total length of the transducer
- T2: Thickness of the drive-unit
- T3: Thickness of the rear mass
- $\lambda/2$: Half wavelength of the resonance frequency
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Claims

- 50 1. A bolt-tightening Langevin-type transducer having a structure in which a drive-unit, formed by laminating together a plurality of piezoelectric elements, made of a lead-free material, and electrode plates, is sandwiched between a front mass and a rear mass, and therein the front mass and the rear mass are fastened together by a fastening bolt inserted into a hole penetrating the drive-unit, **characterized in that** the drive-unit includes four or more piezoelectric elements formed by using an alkali niobate-based ceramic-piezoelectric material, and therein the front mass is formed by using a first-metal material, and the rear mass is formed by using a second-metal material having a specific gravity greater than that of the first-metal material.
- 55 2. A bolt-tightening Langevin-type transducer according to Claim 1, **characterized in that** the piezoelectric element is formed using a sodium-potassium niobate-based ceramic-piezoelectric material.

3. A bolt-tightening Langevin-type transducer according to Claim 1 or 2, **characterized in that** the specific gravity of the second-metal material is twice or more than that of the first-metal material.
- 5 4. A bolt-tightening Langevin-type transducer according to Claim 3, **characterized in that** the specific gravity of the first-metal material is 2.5 or more and 3.5 or less, and that the specific gravity of the second-metal material is 7.0 or more and 9.0 or less.
- 10 5. A bolt-tightening Langevin-type transducer according to any one of Claims 1 to 4, **characterized in that** the total length of the transducer corresponds to half of the wavelength of the resonance frequency, and that the thickness of the drive-unit is less than one third of the total length of the transducer, and that the thickness of the front mass is more than one third of the total length of the transducer.
- 15 6. A bolt-tightening Langevin-type transducer having a structure in which a drive-unit, formed by laminating together a plurality of piezoelectric elements, made of a lead-free material, and electrode plates, is sandwiched between a front mass and a rear mass therein, and that the front mass and the rear mass are fastened together by a fastening bolt inserted into a hole penetrating the drive-unit, **characterized in that** the drive-unit includes four or more piezoelectric elements formed by using an alkali niobate-based ceramic-piezoelectric material, therein the front mass and the rear mass are formed by using a metal material of equal specific gravity, as well as the weight of the rear mass is greater than that of the front mass.
- 20 7. An ultrasonic measuring device for measuring a physical quantity by transmitting and receiving ultrasonic waves, **characterized in that** the ultrasonic measuring device comprises one or more bolt-tightening Langevin-type transducers according to any one of Claims 1 to 6.
- 25 8. An ultrasonic measuring device according to Claim 7, **characterized in that** the ultrasonic measuring device is a fish-detection sensor having a structure of which a plurality of the bolt-tightening Langevin-type transducers are rubber-molded in the same direction.

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FIG. 1

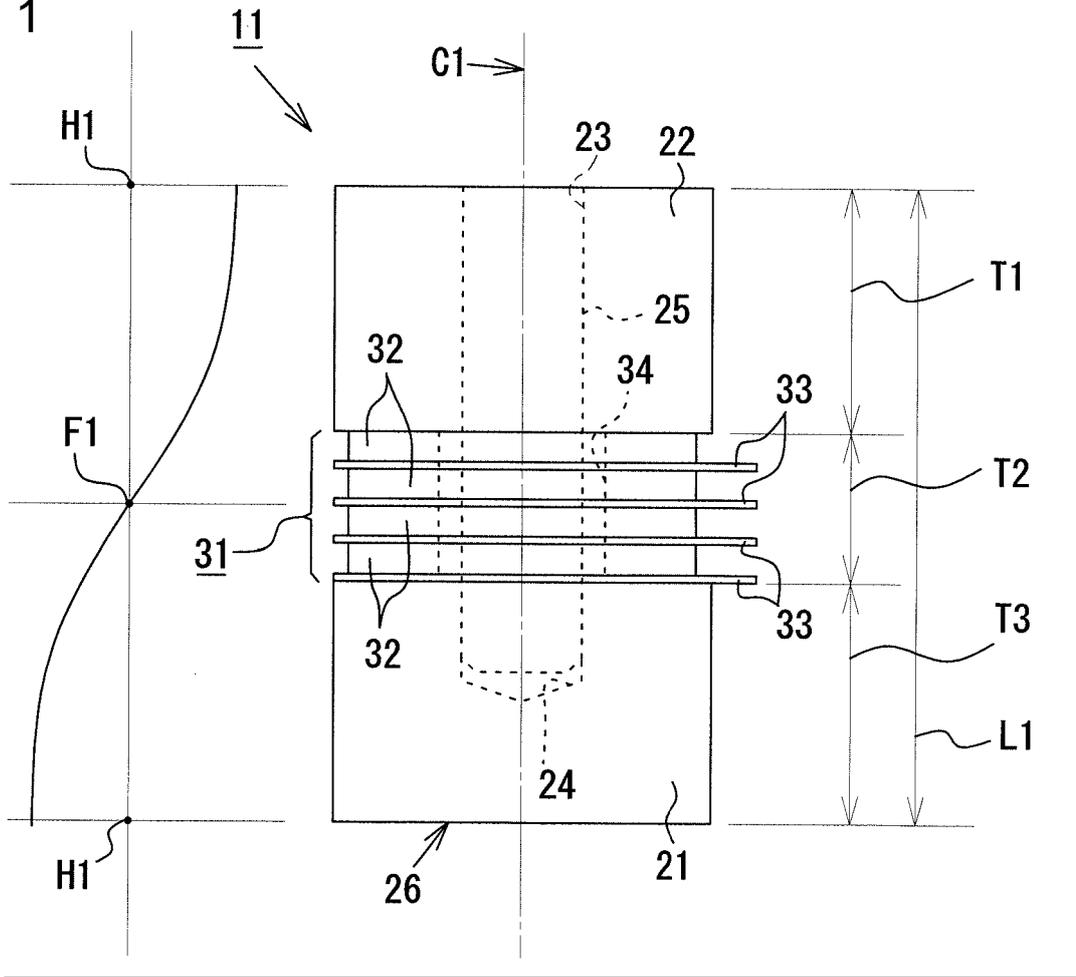


FIG. 2

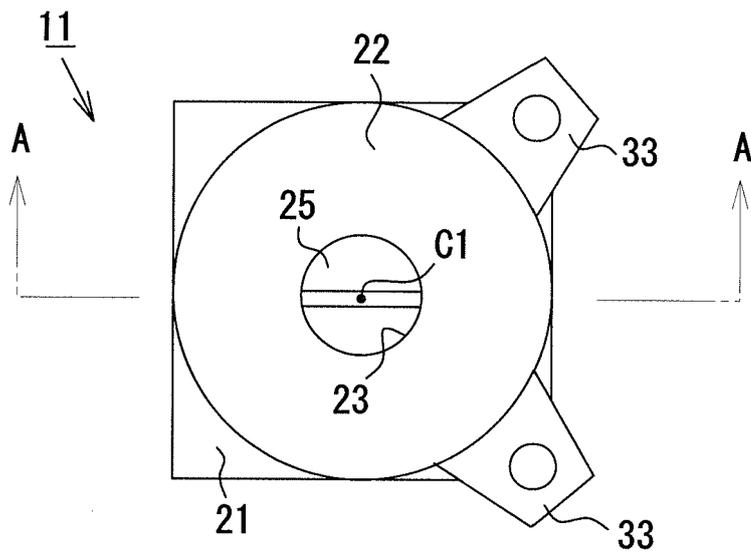


FIG. 3

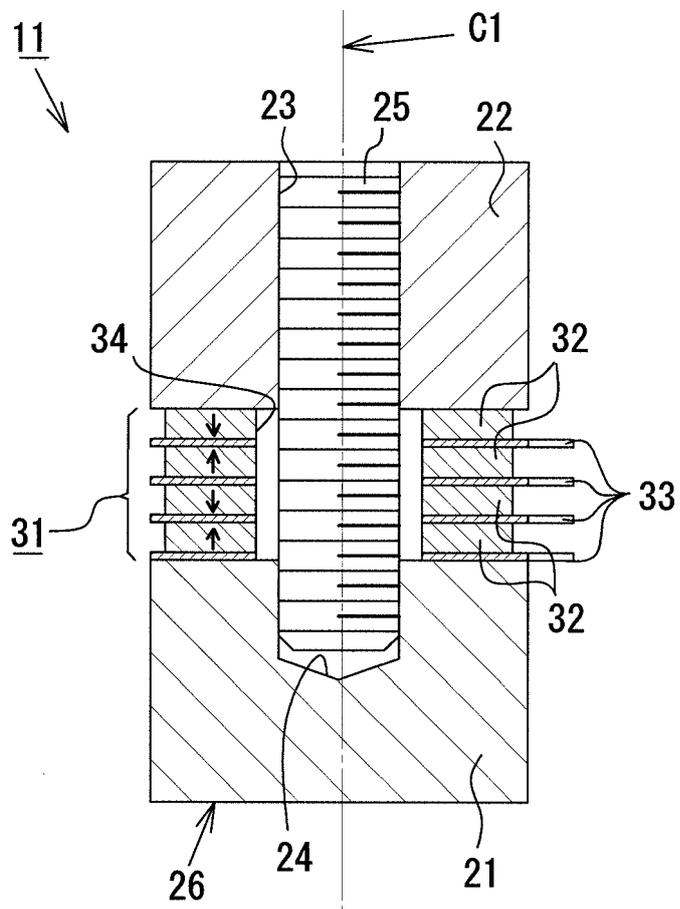


FIG. 4

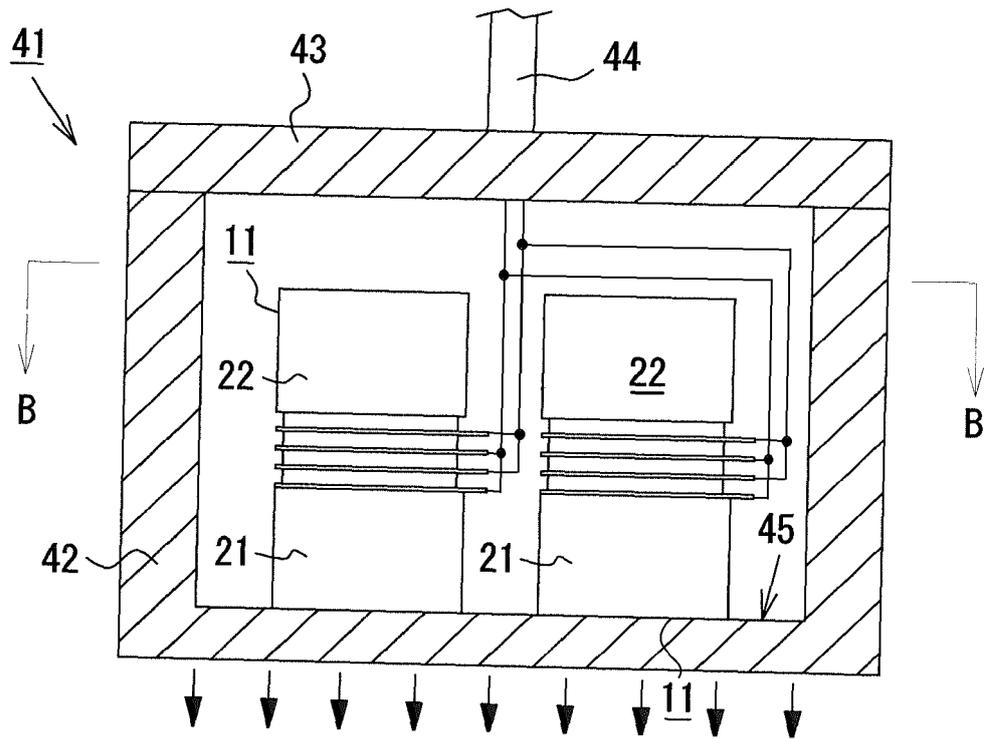


FIG. 5

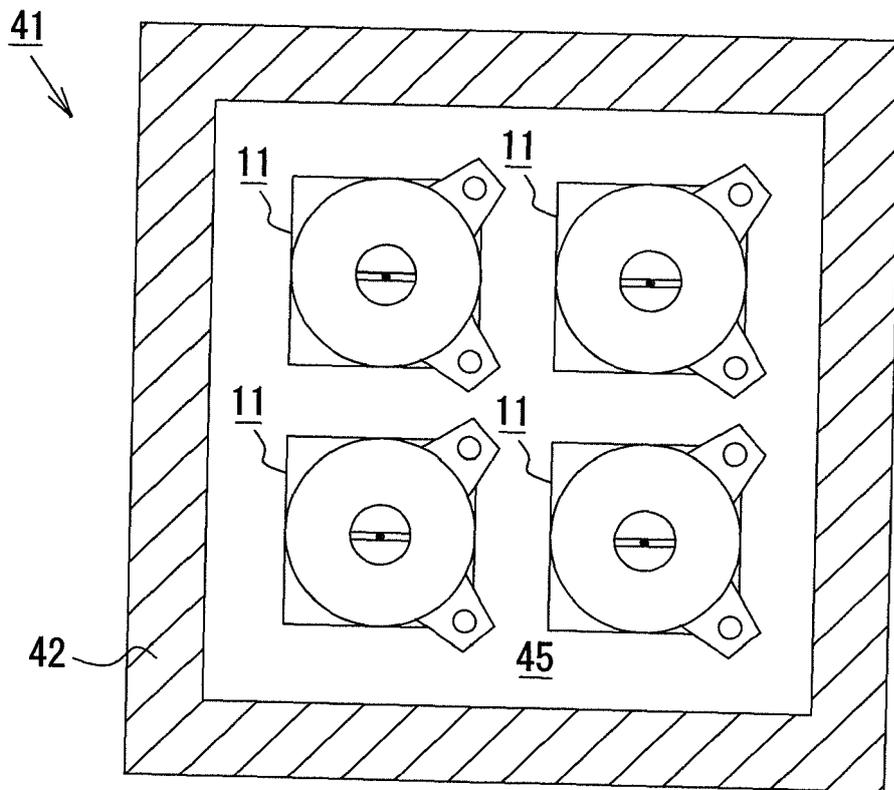


FIG. 6

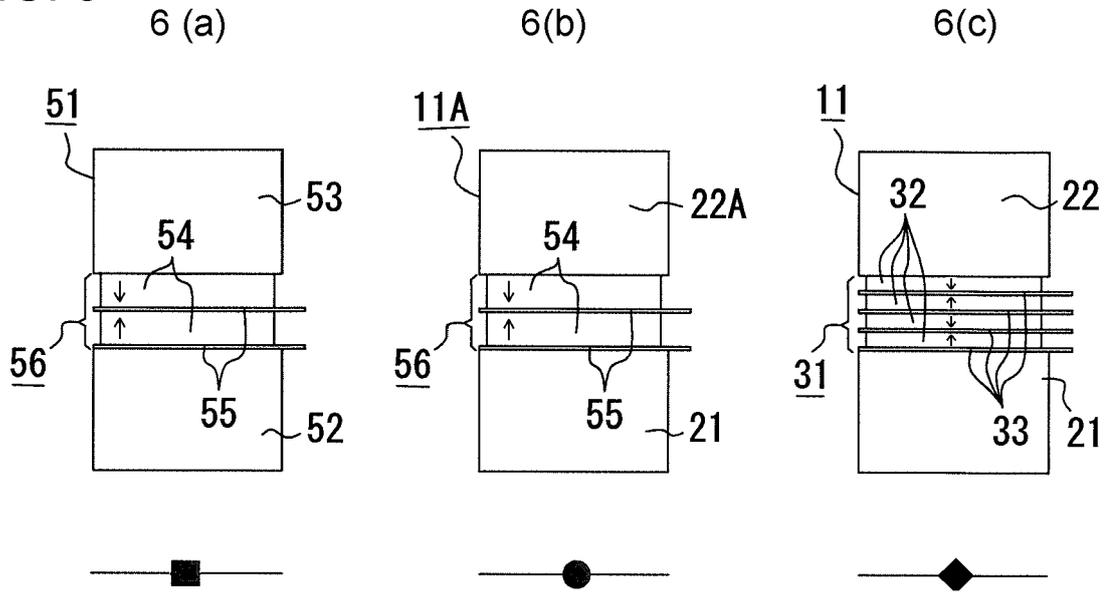


FIG. 7

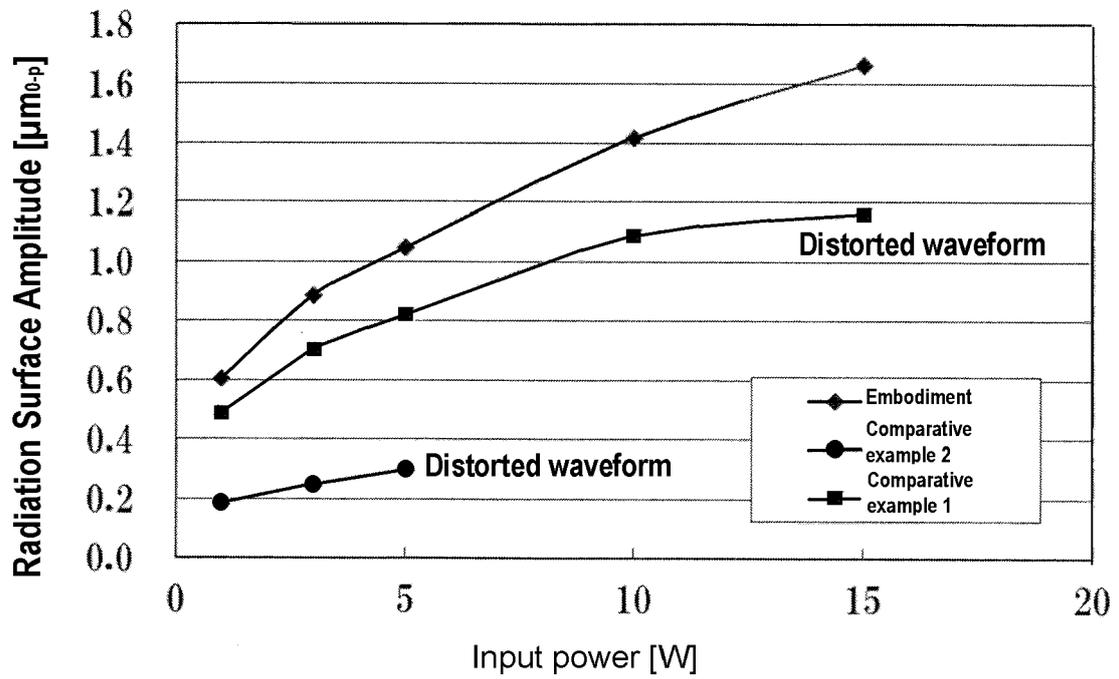


FIG. 8

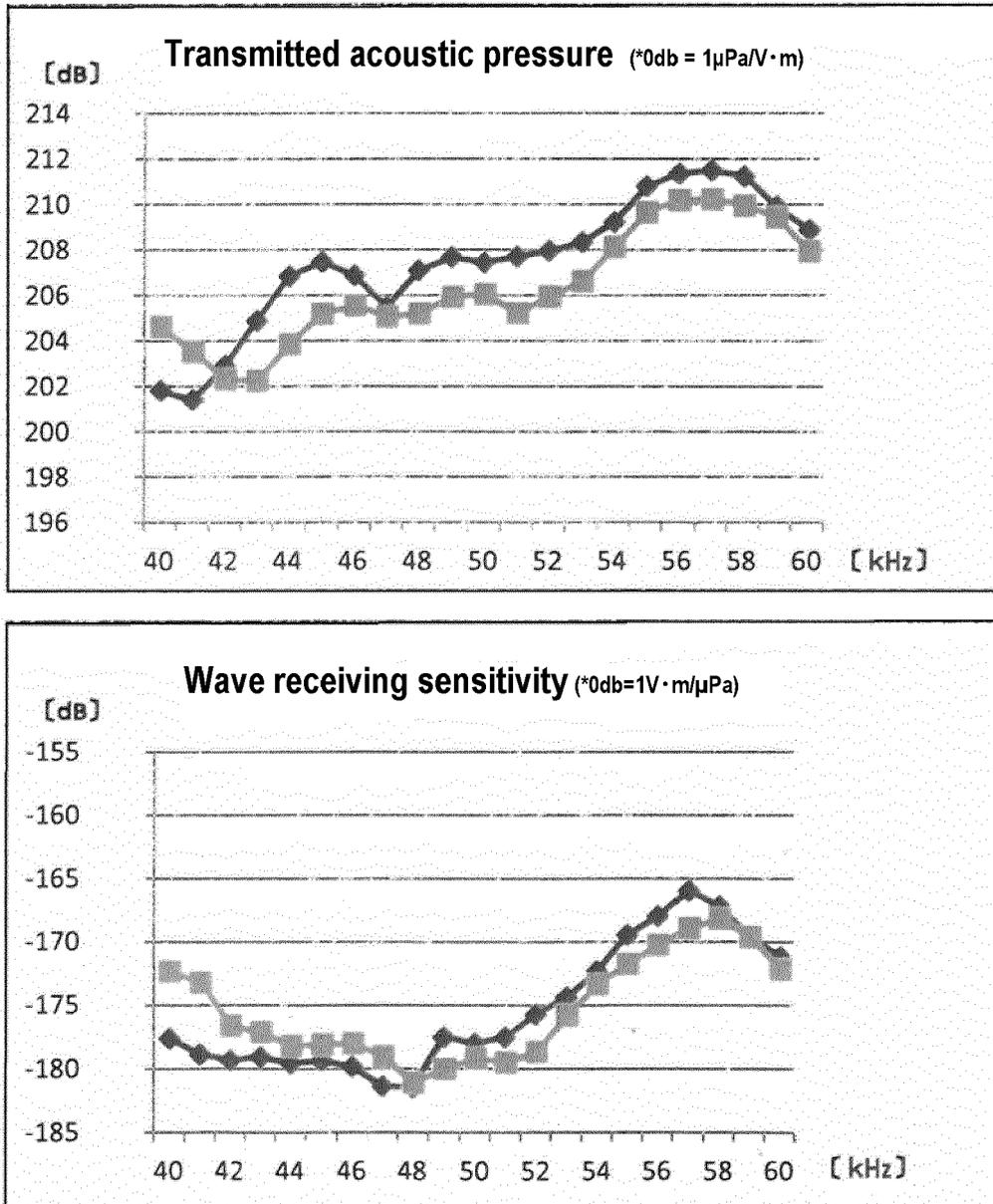
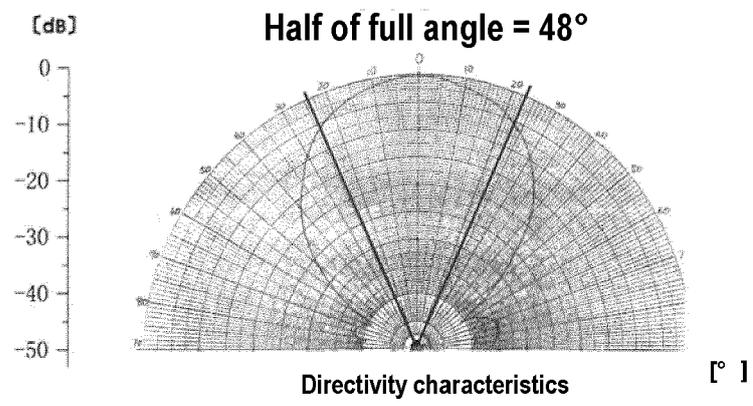
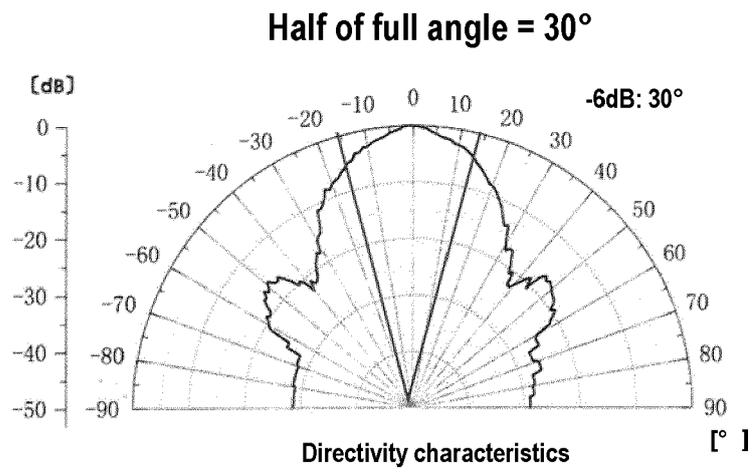


FIG. 9





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