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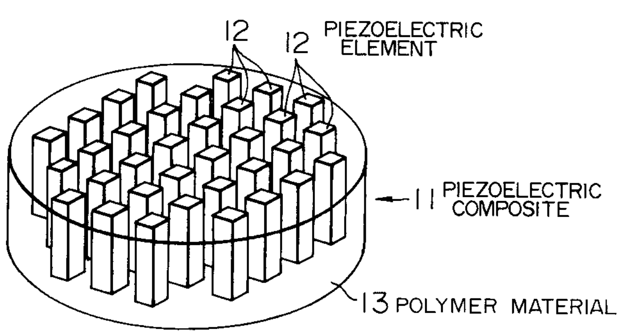
(54) ULTRASONIC PROBE.

(57) An ultrasonic probe for high-resolution ultrasonic imaging is provided. The probe includes an assembly of piezoelectric elements (11), which has a wide frequency range and a self-weighted distribution of ultrasonic amplitudes to attenuate side-lobe levels.

FIG. 2



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TECHNICAL FIELD

The present invention relates to an ultrasonic probe used in a sensor for a sonar, an ultrasonic diagnostic apparatus and the like.

BACKGROUND ART

Recently, a piezoelectric element used in an ultrasonic probe of a sonar or an ultrasonic diagnostic apparatus used for water or a living body employs piezoelectric ceramic having uneven thickness as material thereof to obtain a wide frequency band. Further, there has been studied a method of obtaining an ultrasonic image having high resolution by an improved ultrasonic beam pattern with a reduced side lobe level by means of a shape of electrodes provided in the piezoelectric material or of sound absorbing material.

An example of such an ultrasonic probe is described in JP-A-61-76949. This ultrasonic probe includes a plurality of vibration elements arranged in an array to control an ultrasonic beam. In this ultrasonic probe, an area of each of electrodes of the vibration elements is differed in area or a sound absorbing material provided in a rear surface of the vibration elements is differed in thickness so as to effect weighting (apodization) for reducing unnecessary side lobe level.

The ultrasonic probe includes a plurality of vibration elements 1 arranged in an array to control an ultrasonic beam, wherein each of electrodes 2 of the vibration elements 1 is differed in area as shown in Fig. 1(A), or sound absorbing material 4 disposed in a rear surface of vibration elements 3 is differed in thickness as shown in Fig. 1(B) so as to effect weighting (apodization) for reducing unnecessary side lobe level.

In the above conventional ultrasonic probe, however, it is very difficult in the manufacturing technique to form an ultrasonic beam pattern for each of the vibration elements 1 arranged in an array in considering a proper shape of the electrodes 2, and it is actually impossible to obtain weighting of the vibration elements by differing thickness of the sound absorbing material.

DISCLOSURE OF INVENTION

The present invention is to solve the above conventional problems and it is an object of the present invention to provide an excellent ultrasonic probe in which piezoelectric composite has a wide frequency band characteristic and an ultrasonic amplitude distribution to make it possible to effect weighting in the piezoelectric composite by itself so that the side lobe level is reduced to obtain an ultrasonic image with high resolution.

In order to achieve the object, according to the present invention, there is provided a piezoelectric composite including electrodes formed on both end surfaces thereof and a plurality of piezoelectric elements which are arranged and connected with each other by polymer material and having electromechanical coupling coefficients distributed and varied by differing volume ratios of the piezoelectric elements to the polymer material, and there may be further provided a piezoelectric composite including electrodes formed on both end surfaces thereof and a plurality of piezoelectric elements which are arranged and connected with each other by the polymer material so that the electromechanical coupling coefficients are largest in a middle portion and reducing gradually as approaching to the periphery.

BRIEF DESCRIPTION OF DRAWINGS

Fig. 1(A) is a perspective view schematically illustrating a conventional ultrasonic probe together with amplitude distribution; Fig. 1(B) is a sectional view of the ultrasonic probe of Fig. 1; Fig. 2 is a perspective view schematically illustrating a basic structure of a piezoelectric composite of an ultrasonic probe in embodiments of the present invention; Fig. 3 is a sectional view of the same piezoelectric composite; Fig. 4 is a perspective view of an ultrasonic probe showing a first embodiment of the present invention; Fig. 5 is a sectional view of the ultrasonic probe shown in Fig. 4; Fig. 6 is a plan view schematically illustrating an ultrasonic probe showing a second embodiment of the present invention; Fig. 7 is a sectional view of the ultrasonic probe shown in Fig. 6; Fig. 8 is a graph showing a relation of an electromechanical coupling coefficient versus a volume ratio of piezoelectric ceramic; and Fig. 9 is a sectional view of a piezoelectric composite body showing a third embodiment of the present invention.

BEST MODE FOR CARRYING OUT THE INVENTION

EMBODIMENT 1

Fig. 2 is a perspective view schematically illustrating a basic structure of a piezoelectric composite used in embodiments of the present invention, and Fig. 3 is a sectional view of the piezoelectric composite shown in Fig. 2. In Figs. 2 and 3, numeral 11 denotes a piezoelectric composite and numeral 12 denotes a plurality of piezoelectric elements shaped in a square pillar made of piezoelectric ceramic such as PZT and $PbTiO_3$. Numeral 13 denotes polymer material which is filled between the piezoelectric elements 12 to connect them together, and which is made from silicone rubber, epoxy resin and polyurethane resin, for example. Numerals 14 and 15 denote electrodes disposed on end surfaces of the piezoelectric elements 12 and formed by a method of plating, depositing, sintering or the like. The piezoelectric elements 12 have one-dimensional connection by the electrodes 14 and 15 provided on both of the end surfaces pruned in same level. The polymer material 13 has three-dimensional connection by being filled into gaps among the piezoelectric elements 12. Thus, when a voltage is applied across the electrodes 14 and 15, the piezoelectric composite 11 vibrates mechanically and produces an ultrasonic wave having a frequency corresponding to a thickness t.

As shown in Fig. 3, the piezoelectric elements 12 are arranged so that intervals P between the elements are fixed, while volume ratios of the piezoelectric elements 12 to the polymer material 13 are different. For example, the volume ratios are set to have different volume ratios in three kinds of areas A, B and C in which the volume fraction of the piezoelectric ceramic is largest in the middle portion A and is getting the smaller in the peripheral portions B and C, the nearer to the periphery, so that the electromechanical coupling coefficients are distributed and varied.

A relation of the electromechanical coupling coefficient k_t versus the volume fraction

V of the piezoelectric ceramic forming the piezoelectric element versus the whole including the polymer material is shown in Fig. 8, which shows a curve in the case where PZT 5 is used as the piezoelectric ceramic and epoxy resin is used as the polymer material. In Fig. 8, when the volume ratio V of the piezoelectric ceramic is varied from 10 to 20 and 30%, for example, the electromechanical coupling coefficient k_t varies from 50 to 60 and 64% respectively. Thus, when the volume ratios 30, 20 and 10% of this example correspond to the volume ratios of the portions A, B and C of the piezoelectric composite 11 shown in Fig. 3, respectively, the electromechanical coupling coefficient of the piezoelectric composite 11 is distributed so that it is as largest as 64% in the middle portion and is getting smaller as 60 and 50% in the peripheral portions B and C. When the electromechanical coupling coefficient is distributed in this manner, an amplitude of the ultrasonic wave produced by the piezoelectric composite 11 can be weighted. More particularly, sound pressure of the ultrasonic wave is produced high by the portion A of the piezoelectric composite 11 and produced gradually lowered by the portions B and C so that the amplitude of the ultrasonic wave is weighted (apodized) in a single piezoelectric composite 11 itself to reduce the side lobe level of an ultrasonic beam pattern produced by the piezoelectric composite 11 and thereby an ultrasonic image having high resolution may be obtained.

Figs. 4 and 5 show a first embodiment of the ultrasonic probe according to the present invention using the piezoelectric composite having the above structure. In Figs. 4 and 5, numeral 21 denotes a piezoelectric composite having the same structure as the above basic structure, 22 a plurality of piezoelectric elements which are arranged straight with one-dimensional connection and have the electromechanical coupling coefficient varied by changing the volume ratio, 23 polymer material such as silicone rubber, epoxy resin or polyurethane resin and filled into gaps between the piezoelectric elements 22 to have three-dimensional connection, 24 arrayed electrodes arranged into a plurality of rows and formed on one end surface of the piezoelectric elements 22 by a method of plating, depositing, sintering or the like, and 25 a common electrode formed on the other end surface of the piezoelectric elements 22. Numeral 26 denotes an acoustic matching layer disposed on the side of the common electrode 25 for propagating an ultrasonic wave effectively, and 27 an acoustic lens disposed on the side of the acoustic matching layer 26 for focusing an ultrasonic beam. The acoustic lens 27 is provided if necessary. Numeral 28 denotes backing material disposed on the side of the arrayed electrodes 24 for absorbing an ultrasonic wave and holding the piezoelectric composite 21.

The structure of such a piezoelectric composite 21 is the same as that used in a so-called arrayed ultrasonic probe and its operation is also the same. More particularly, a voltage is applied to the plurality of arrayed electrodes 24a, 24b, 24c, ... 24n provided in the piezoelectric composite 21 in a manner that a certain group of the electrodes is provided with a voltage supply having a time delay. Thus, the ultrasonic wave produced by the piezoelectric composite is converged to a certain distance. As the groups are scanned channel by channel, the ultrasonic wave reflected by an inside portion of a living body is received. The received ultrasonic wave is image-processed to be displayed on a display at a real time for diagnosis of the inside portion of the living body.

Fig. 5 is a sectional view of the piezoelectric composite 21 cut in the direction perpendicular to the arrayed direction of the array electrodes 24. The piezoelectric elements 22 having different volume ratios are arranged in this direction. More particularly, the piezoelectric elements 22a having a largest volume ratio are arranged in the middle portion A so that the electromechanical coupling coefficient is largest in the middle portion A and the piezoelectric elements 22b and 22c having the volume ratios which are gradually reduced are arranged in the peripheral portions B and C so that the electromechanical coupling coefficients are gradually lowered as approaching to the periphery.

For example, when PZT 5 and epoxy resin are used for the piezoelectric ceramic and the polymer material respectively as described in Fig. 8, and three kinds of volume ratios of the piezoelectric elements 22 are provided, assuming that the volume ratios of the piezoelectric elements 22 of the portions A, B and C of Fig. 4 are 30, 20 and 10%, respectively, the electromechanical coupling coefficients of the portions A, B and C are 64, 60 and 50%, respectively.

With such a structure, the radiation amplitude of the ultrasonic wave produced by the piezoelectric elements 22a in the middle portion A is larger corresponding to the larger electromechanical coupling coefficient and the radiation amplitude of the ultrasonic wave produced by the peripheral portions B and C is lower corresponding to the lower electromechanical coupling coefficient as approaching to the periphery. Accordingly, weighting (apodizing) of the amplitude can be made in the perpendicular direction to the arraying direction of the arrayed electrodes 24 and then the side lobe level can be reduced to obtain an ultrasonic image having high resolution.

In the embodiment 1, description is made for the case where three kinds of volume ratios of the piezoelectric elements are provided, while even if two or four or more kinds of volume ratios is provided, the same effects can be attained.

Further, in the embodiment 1, the arrayed ultrasonic probe having a plurality of arrayed electrodes 24 is described, while even if a piezoelectric composite 21 is also divided at the same intervals as well as the arrayed electrodes 24a, 24b, 24c, ... 24n and arranged in an array, the same effects can be obtained.

EMBODIMENT 2

A second embodiment of the present invention is described with reference to Figs. 6 and 7. In Figs. 6 and 7, numeral 31 denotes a piezoelectric composite having the same structure as the basic structure described above, and numeral 32 denotes a plurality of piezoelectric elements each of which is formed into a square pillar and having the electromechanical coupling coefficients varied by changing the volume ratios with one-dimensional connection and which are divided into groups each having the same volume ratio and arranged concentrically. Numeral 33 denotes polymer material such as silicone rubber, epoxy resin, polyurethane resin or the like which is filled into gaps between the piezoelectric elements 32 and has three-dimensional connection. Numeral 34 denotes concentrically arrayed electrodes each of which is formed on one end surfaces of the piezoelectric elements 32 for each group by plating, depositing, sintering or the like. Numeral 35 denotes a common electrode disposed on the other end surfaces of the piezoelectric elements 32. Numeral 36 denotes an acoustic matching layer disposed on the side of the common electrode 35 for propagating an ultrasonic wave effectively, and numeral 37 denotes backing material disposed on the side of the arrayed electrodes 34 for absorbing an ultrasonic wave and holding the piezoelectric composite 31.

The arrayed electrodes 34 include a plurality of electrodes 34a, 34b, 34c, ... 34n arranged concentrically, and piezoelectric elements 32a, 32b, 32c, ... 32n having electromechanical coupling coefficients varied by changing volume ratios are grouped and arranged nearly corresponding to the electrodes 34. More particularly, the piezoelectric elements 32a having the largest volume ratio are arranged in the middle portion A corresponding to the electrode 34a so that the electromechanical coupling coefficient is largest in the middle portion A and the piezoelectric elements 32b, 32c, ... 32n having the volume ratios which are gradually lowered correspondingly are arranged in the peripheral portions so that the electromechanical coupling coefficients are gradually decreased as approaching to the periphery.

For example, in the same manner as the embodiment 1, when PZT 5 as the piezoelectric ceramic and epoxy resin as the polymer material are used and three kinds of volume ratios of the piezoelectric elements 32 are provided as described in Fig. 8, and when it is assumed that the volume ratio of the piezoelectric elements 32a of the portion A in Fig. 7 is 30% and the volume ratios of the piezoelectric elements of its peripheral portions in Fig. 7 are 20 and 10%, progressively, the electromechanical coupling coefficients of the central portion A and the peripheral portions are 64, 60 and 50%, respectively.

The ultrasonic probe structured as above is a so-called annular-arrayed ultrasonic probe, and when the same voltage is applied to each of arrayed electrodes 34 of the piezoelectric composite 31, the amplitude distribution of ultrasonic wave may be attained such that the radiation amplitude of ultrasonic wave produced from the central portion A is largest and the radiation amplitude of ultrasonic wave from the peripheral portions is progressively reduced as approaching to the periphery. Accordingly, the amplitude can be weighted in any radial direction and then the side lobe level can be reduced to obtain an ultrasonic image having high resolution.

In the embodiment 2, the piezoelectric elements 32 hav corresponding volume ratio to each of the arrayed electrodes 34 disposed in the piezoelectric composite 31, while the group of the piezoelectric elements 32 having same volume ratio is not required to exactly correspond to each portion of the arrayed electrodes 34 but the volume ratios of the piezoelectric elements are to be set substantially so that the electromechanical coupling coefficients are progressively lowered from the central portion to the periphery.

Further, in the precedent embodiments, description has been made to the case where the piezoelectric ceramic of PZT system and $PbTiO_3$ system is used as the piezoelectric elements having different volume ratios, while even porous piezoelectric ceramic, three-component system piezoelectric ceramic or monocrystal such as $LiNbO_3$ and $LiTaO_3$, or combination thereof may be used with the same effects.

EMBODIMENT 3

Fig. 9 is a perspective view schematically illustrating a basic structure of a piezoelectric composite usable in embodiments of the present invention.

In Fig. 9, numeral 11 denotes a piezoelectric composite and numeral 12 denotes a plurality of piezoelectric elements including piezoelectric elements 12a and 12b each of which has a different frequency constant and is formed into a square pillar having the same length and size and which are juxtaposed alternately in the mutually orthogonal direction. Numeral 13 denotes polymer material filled between the piezoelectric elements 12a and 12b to couple each other, and silicone rubber, epoxy resin or polyurethane resin, for example, is used therefor. Numerals 14 and 15 denote electrodes formed on both of end surfaces of the piezoelectric elements 12 by a method of plating, depositing or sintering. The piezoelectric elements 12a and 12b have one-dimensional connection by providing the electrodes 14 and 15 on both of the end surfaces pruned in same level. The polymer material 13 has three-dimensional connection by filling the material into gaps among the piezoelectric elements 12. Thus, when a voltage is applied to the electrodes 14 and 15, the piezoelectric composite 11 is vibrated mechanically and produces an ultrasonic wave having a corresponding frequency to a thickness t.

The piezoelectric composite having the plurality of piezoelectric elements combined integrally with each other by the polymer material is named a so-called 1-3 type piezoelectric composite and is known by the paper (Proc. IEEE, 1985, Ultrasonics Symp. pp. 643-647), for example. However, the conventional piezoelectric composite includes the piezoelectric elements having the same frequency constant, whereas the piezoelectric composite of the invention includes the piezoelectric elements 12 having different frequency constants, and groups of the piezoelectric elements 12a and 12b having different frequency constants being arranged alternately in a two-dimensional plane. Therefore, the frequency band is wider and a shorter pulse is obtained according to the invention so that the ultrasonic image having higher resolution can be obtained. The frequency constants of the elements may be more than two different kinds and its arrangement may be irregular.

This piezoelectric composite is used in the ultrasonic probe shown in Figs. 4 and 5 described of the first embodiment. In the piezoelectric composite 21 shown in Figs. 4 and 5, the piezoelectric elements 22 having different electromechanical coupling coefficients are arranged in the direction perpendicular to the arrangement direction of the arrayed electrodes 24. More particularly, the piezoelectric elements 22a having the largest electromechanical coupling coefficient are disposed in the middle portion A and the piezoelectric elements 22b and 22c are disposed in the peripheral portions B and C respectively so that the electromechanical coupling coefficients are gradually reduced as approaching to the periphery.

As to the three kinds of piezoelectric elements 22a, 22b and 22c each having a different electromechanical coupling coefficient, the piezoelectric elements 22a in the middle portion A comprise, for example, piezoelectric ceramic N-21 (its electromechanical coupling coefficient $k\,33 = 0.73$) of PZT system available from TOHOKU KINZOKU CO., the piezoelectric elements 22b in its peripheral portion B comprise piezoelectric ceramic N-8 (its electromechanical coupling coefficient $k\,33 = 0.67$) of PZT system available from TOHOKU KINZOKU CO., and the piezoelectric elements 22c in the outermost portion C comprise piezoelectric ceramic C-24 (its electromechanical coupling coefficient $k\,33 = 0.54$) of $PbTiO_3$ system available from TOSHIBA CERAMIC CO. The polymer material 23 such as silicon rubber, epoxy resin or polyurethane resin is filled into gaps among the piezoelectric elements 22a, 22b and 22c to thereby form the piezoelectric composite 21.

With such a structure, the radiation amplitude of the ultrasonic wave produced by the piezoelectric elements 22a in the middle portion A is large since the electromechanical coupling coefficient thereof is large, while the radiation amplitude of the ultrasonic wave produced by the piezoelectric elements in the peripheral portions B and C is small in accordance with the lowered electromechanical coupling coefficients as approaching to the periphery. Accordingly, weighting (apodizing) of the amplitude can be made in the direction perpendicular to the arrangement direction of the arrayed electrodes 24 and the side lobe level can be reduced to obtain the ultrasonic image having high resolution.

In the embodiment 3, piezoelectric ceramic is used for the three kinds of piezoelectric elements 22a, 22b and 22c having different electromechanical coupling coefficients, while piezoelectric material of a combination of piezoelectric ceramic and monocrystal such as $LiNbO_3$ and $LiTaO_3$ or porous piezoelectric ceramic may be used therefor to obtain the same effects. Further, the electromechanical coupling coefficients are not limited to be three kinds, and two or four or more kinds of electromechanical coupling coefficients may be used.

In the embodiment 3, the arrayed ultrasonic probe having the plurality of arrayed electrodes 24 has been described, while even the piezoelectric composite 21 may be divided at the same intervals as the arrayed electrodes 24a, 24b, 24c, ... 24n and arranged in an array to obtain the same effects.

EMBODIMENT 4

A fourth embodiment of the present invention used with the above piezoelectric composite is now described.

The piezoelectric composite 31 described in the embodiment 3 is utilized for the annular arrayed ultrasonic probe shown in Figs. 6 and 7.

Numeral 32 denotes a plurality of piezoelectric elements each of which is formed into a square pillar and which have one-dimensional connection and are divided into groups each having different electromechanical coupling coefficient and arranged concentrically, numeral 33 denotes polymer material such as silicone rubber, epoxy resin or polyurethane resin filled into gaps among the piezoelectric elements 32 and having three-dimensional connection, numeral 34 denotes arrayed electrodes formed on one end surface of the grouped piezoelectric elements 32 concentrically by a method of plating, depositing or sintering, and numeral 35 denotes a common electrode formed on the other end surface of the piezoelectric elements 32. Numeral 36 denotes an acoustic matching layer disposed on the side of the common electrode 35 for propagating an ultrasonic wave efficiently, and numeral 37 denotes backing material disposed on the side of the arrayed electrodes 34 for absorbing an ultrasonic wave and holding the piezoelectric composite 31. Piezoelectric ceramic such as of PZT system or $PbTiO_3$ system is used as the piezoelectric elements 32.

The arrayed electrodes 34 include a plurality of electrodes 34a, 34b, 34c, ... 34n arranged concentrically, and piezoelectric elements 32a, 32b, 32c, ... 32n having different electromechanical coupling coefficients are divided into groups and arranged approximately in alignment with the electrodes 34. In other words, the piezoelectric elements 32a having the largest electromechanical coupling coefficient are arranged in the central portion A corresponding to the electrode 34a and the piezoelectric elements 32b, 32c, ... 32n are arranged so that the electromechanical coupling coefficients are gradually reduced as approaching to the periphery.

The ultrasonic probe structured as above is a so-called annular arrayed ultrasonic probe, and when the same voltage is applied to each of arrayed electrodes 34 of the piezoelectric composite 31, the amplitude distribution of the ultrasonic wave can be attained in which the radiation amplitude of the ultrasonic wave produced from the central portion A is largest and the radiation amplitude is gradually lowered as approaching to the periphery. Accordingly, weighting of the amplitude can be made in any radial direction and the side lobe level can be reduced to thereby obtain the ultrasonic image having high resolution.

In the embodiment 4, piezoelectric ceramic is utilized as the piezoelectric elements having different electromechanical coupling coefficients, while even piezoelectric material of a combination of piezoelectric ceramic with monocyrstal such as $LiNbO_3$ and $LiTaO_3$ or porous piezoelectric ceramic may be utilized therefor to obtain the same effects.

In the embodiment 4, the piezoelectric elements 32 having different electromechanical coupling coefficients are arranged corresponding to the arrayed electrodes 34 disposed in the piezoelectric composite 31, while the electromechanical coupling coefficients of the piezoelectric elements 32 are not required to correspond exactly to the arrayed electrodes 34 but the piezoelectric elements are to be arranged so that the electromechanical coupling coefficients are gradually lowered from the central portion to the peripheral portions.

INDUSTRIAL APPLICABILITY

As apparent from the foregoing description, the present invention provides a piezoelectric composite including electrodes formed on both end surfaces thereof, a plurality of piezoelectric elements which are arranged and coupled with each other by polymer material and electromechanical coupling coefficients distributed and varied by changing volume ratios of the piezoelectric elements versus polymer material and accordingly the electromechanical coupling coefficients of a single piezoelectric composite can be varied partially. Further, the piezoelectric composite itself can possess the amplitude distribution that the amplitude is large in the central portion and is gradually smaller as approaching to the periphery.

In addition, since there is provided a piezoelectric composite including electrodes formed on the both end surfaces thereof, a plurality of piezoelectric elements which are arranged so that the electromechanical coupling coefficients are largest in the central portion and gradually reduced as approaching to the periphery and are coupled with each other by the polymer material, the amplitude distribution that the radiation amplitude of the ultrasonic wave is large in the central portion and is gradually lowered from the central portion to the peripheral portions and accordingly an ultrasonic beam pattern having reduced side lobe level can be formed and the ultrasonic image having higher resolution can be obtained.

Claims

1. An ultrasonic probe comprising a piezoelectric composite including electrodes formed on both end surfaces thereof, a plurality of piezoelectric elements which are arranged and coupled with each other by organic high-molecular material, said piezoelectric composite having distributed amplitudes of ultrasonic wave.

2. An ultrasonic probe according to Claim 1, wherein said piezoelectric composite has electromechanical coupling coefficients distributed and varied by changing volume ratios of said piezoelectric elements to said polymer material.

3. An ultrasonic probe according to Claim 1, wherein volume ratios of said piezoelectric elements included in said piezoelectric composite are set so that electromechanical coupling coefficient is largest in a middle portion and the electromechanical coupling coefficient is gradually lowered as approaching to a periphery.

4. An ultrasonic probe according to Claim 3, wherein said piezoelectric elements have one-dimensional connection and said polymer material has three-dimensional connection.

5. An ultrasonic probe according to Claim 4, wherein said piezoelectric elements are piezoelectric ceramic.

6. An ultrasonic probe according to Claim 1, wherein said piezoelectric composite includes two or more kinds of piezoelectric elements having different electromechanical coupling coefficients and which are arranged and coupled by polymer material.

7. An ultrasonic probe according to Claim 1, wherein said piezoelectric composite includes electrodes formed on both surfaces thereof, a plurality of piezoelectric elements which are arranged and coupled by polymer material so that electromechanical coupling coefficient is largest in a middle portion and the electromechanical coupling coefficient is gradually lowered as approaching to the periphery.

8. An ultrasonic probe according to Claim 7, wherein said piezoelectric elements have one-dimensional connection and said polymer material has three-dimensional connection.

9. An ultrasonic probe comprising piezoelectric composites including a plurality of piezoelectric elements arranged in a linear configuration and connected by polymer material and having volume ratios to said polymer material which are set so that electromechanical coupling coefficient is largest in a middle portion and the electromechanical coupling coefficient is gradually lowered as approaching to the periphery, said piezoelectric composite being juxtaposed in a direction perpendicular to the arrangement direction of said piezoelectric elements and having one end surface on which a plurality of arrayed electrodes are provided in the juxtaposition direction and the other end surface on which a common electrode is provided.

10. An ultrasonic probe according to Claim 9, wherein said piezoelectric elements have one-dimensional connection and said organic high-molecular material has three-dimensional connection.

11. An ultrasonic probe according to Claim 10, wherein said piezoelectric elements are piezoelectric ceramic.

12. An ultrasonic probe comprising a piezoelectric composite including a plurality of piezoelectric elements arranged concentrically and coupled by polymer material and having volume ratios to said polymer material which are divided into groups and are set with electromechanical coupling coefficient so that electromechanical coupling coefficient is largest in a central portion and the electromechanical coupling coefficient is gradually lowered as approaching to the periphery, said piezoelectric composite having one end surface on which a plurality of arrayed electrodes are provided concentrically and approximately in alignment with said grouped piezoelectric elements and the other

end surface on which a common electrode is provided.

13. An ultrasonic probe according to Claim 12, wherein said piezoelectric elements have one-dimensional connection and said polymer material has three-dimensional connection.

14. An ultrasonic probe according to Claim 13, wherein said piezoelectric elements are piezoelectric ceramic.

15. An ultrasonic probe comprising a piezoelectric composite including a plurality of piezoelectric elements arranged in a linear configuration and connected by polymer material so that electromechanical coupling coefficient is largest in a middle portion and the electromechanical coupling coefficient is gradually lowered as apporaching to a periphery, said piezoelectric composite being juxtaposed in a direction perpendicular to the arrangement direction of said piezoelectric elements and having one end surface on which a plurality of arrayed electrodes are provided in the juxtaposition direction and the other end surface on which a common electrode is provided.

16. An ultrasonic probe according to Claim 15, wherein said piezoelectric elements have one-dimensional connection and said polymer material has three-dimensional connection.

17. An ultrasonic probe according to Claim 16, wherein said piezoelectric elements are piezoelectric ceramic.

18. An ultrasonic probe according to any of Claims 15 to 16, wherein frequency constant of said piezoelectric elements is two or more different kinds.

19. An ultrasonic probe comprising a piezoelectric composite including a plurality of grouped piezoelectric elements arranged concentrically and connected by polymer material so that electromechanical coupling coefficient is largest in a central portion and the electromechanical coupling coefficient is gradually lowered as approaching to a periphery, said piezoelectric composite having one end surface on which a plurality of arrayed electrodes are provided concentrically in alignment with said grouped piezoelectric elements and the other end surface on which a common electrode is provided.

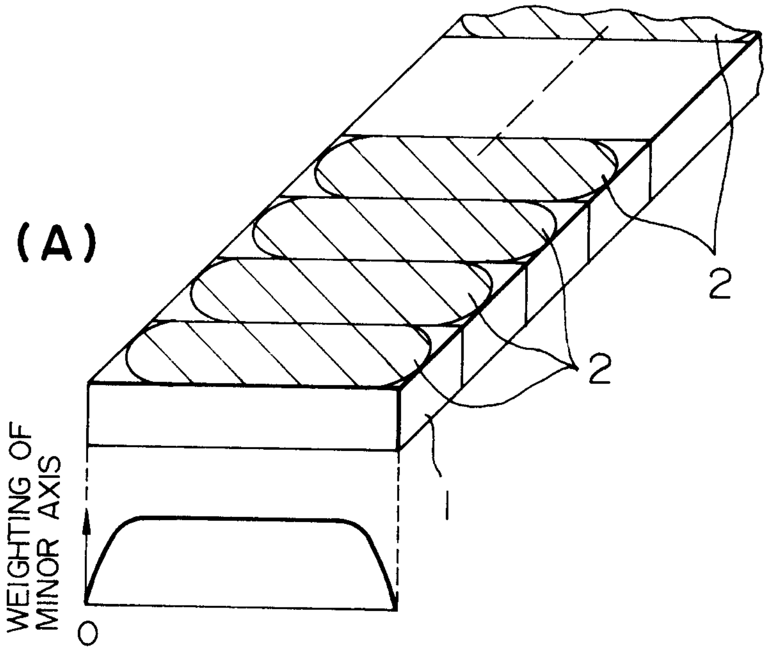
20. An ultrasonic probe according to Claim 19, wherein said piezoelectric elements have one-dimensional connection and said polymer material has three-dimensional connection.

21. An ultrasonic probe according to Claim 20, wherein said piezoelectric elements are piezoelectric ceramic.

22. An ultrasonic probe according to any of Claims 19 to 21, wherein frequency constant of said piezoelectric elements is two or more different kinds.

FIG. 1

(A)



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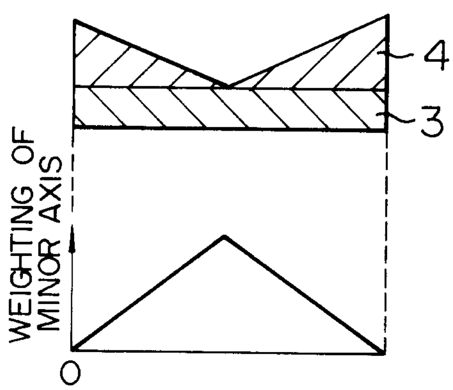
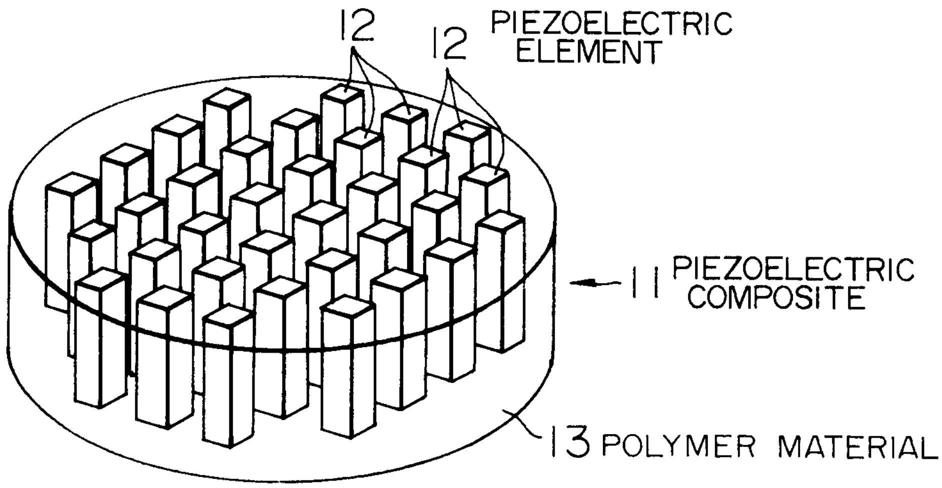


F I G. 2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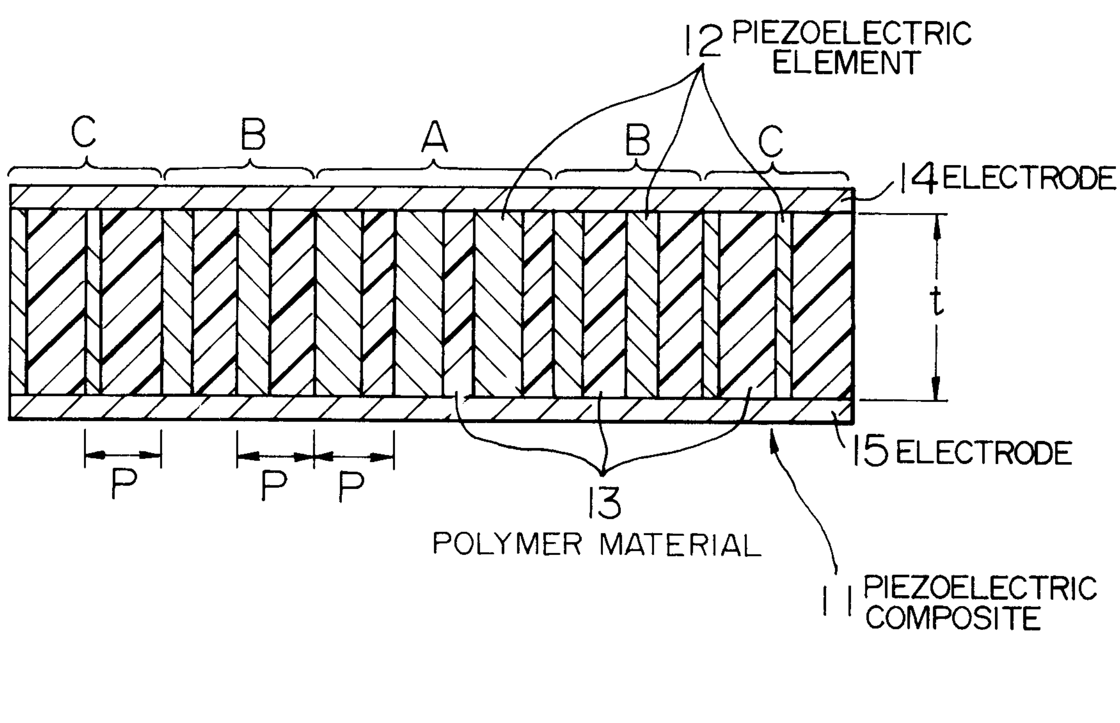
11 PIEZOELECTRIC COMPOSITE
13 POLYMER MATERIAL

F I G. 3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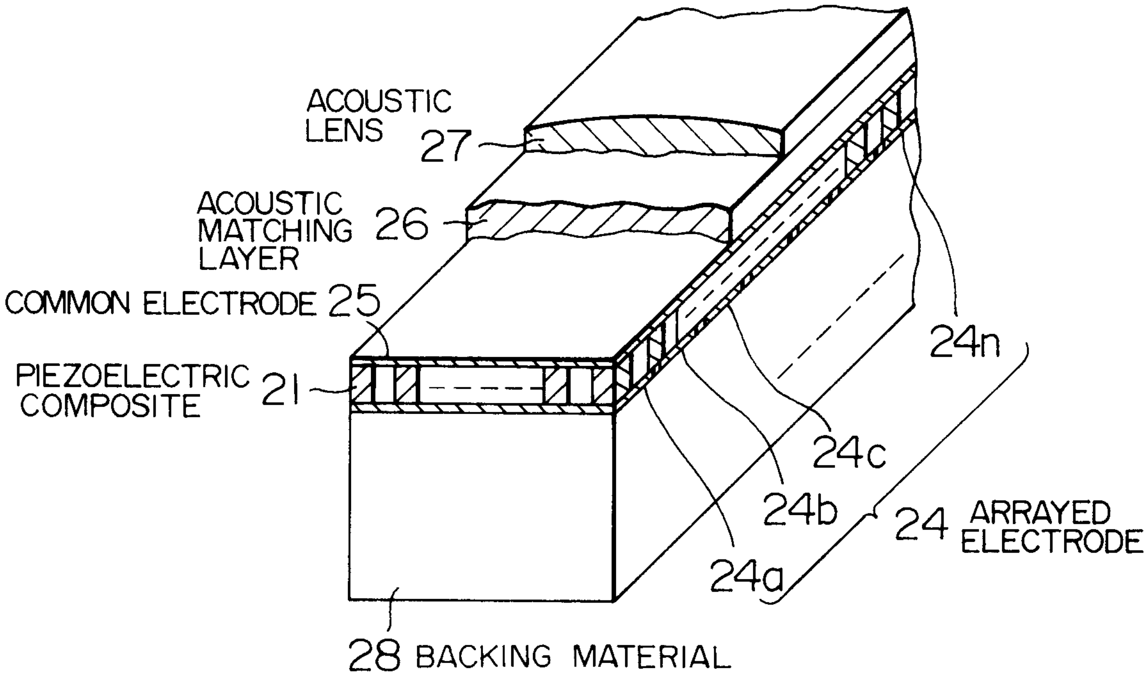
F I G. 4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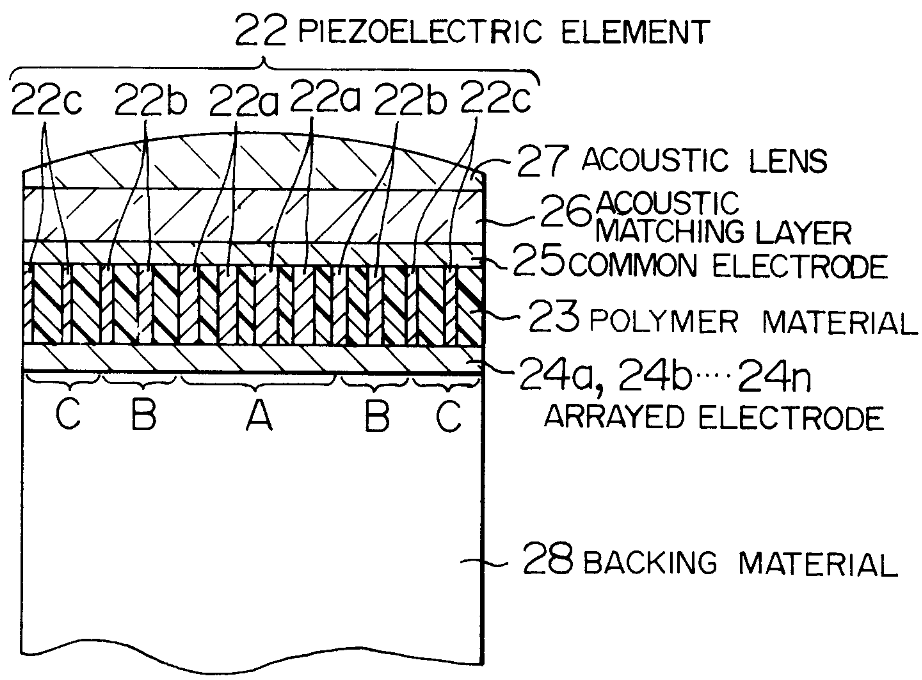
28 BACKING MATERIAL

F I G. 5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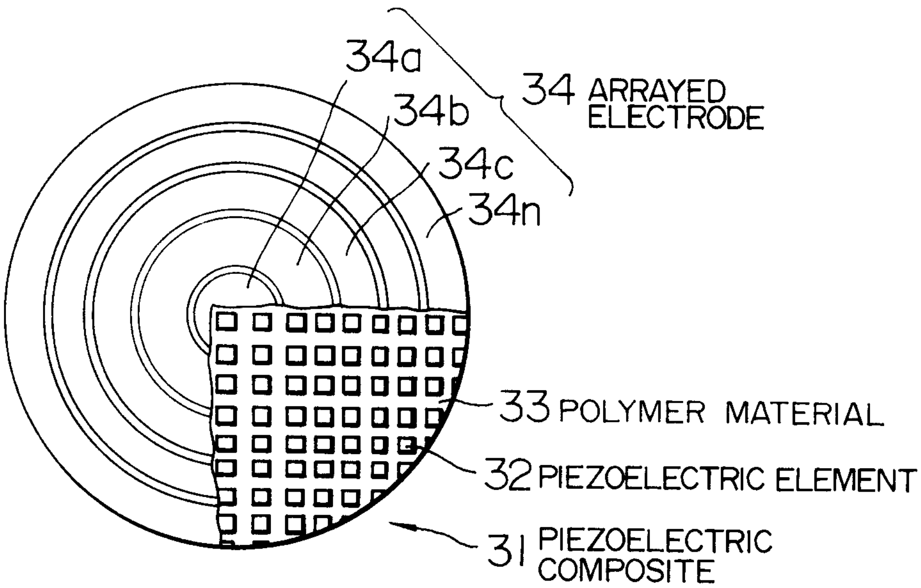
F I G. 6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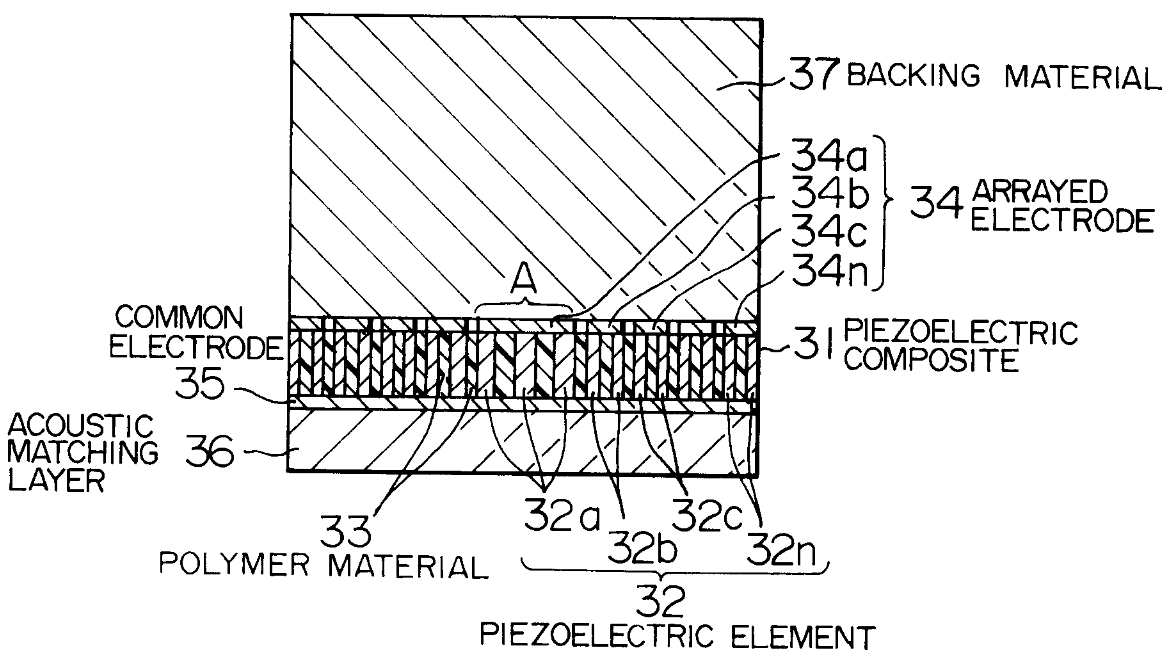
F I G. 7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32c
32n
32
PIEZOELECTRIC ELEMENT

FIG. 8

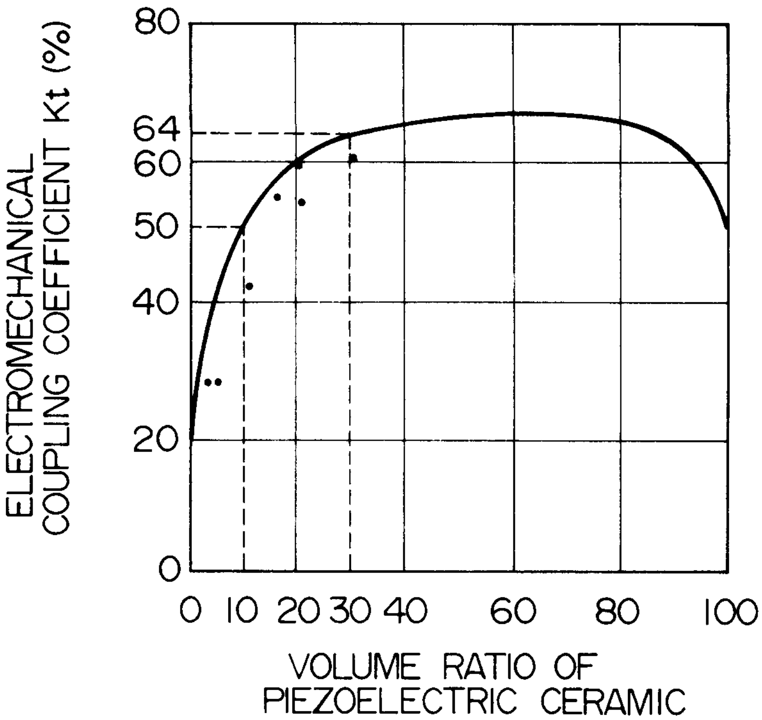
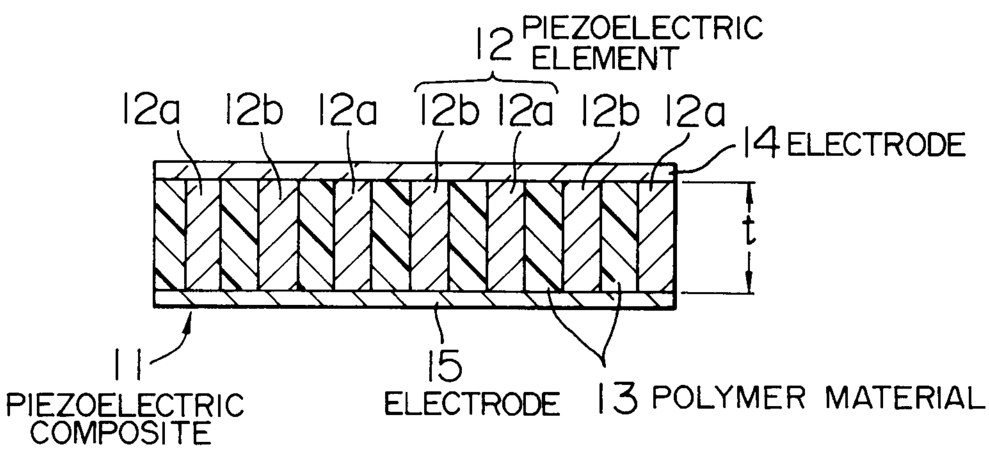

ELECTROMECHANICAL COUPLING COEFFICIENT Kt (%)
80
64
60
50
40
20
0
0 10 20 30 40 60 80 100
VOLUME RATIO OF PIEZOELECTRIC CERAMIC

FIG. 9


12 PIEZOELECTRIC ELEMENT
12a 12b 12a 12b 12a 12b 12a
14 ELECTRODE
t
11
PIEZOELECTRIC COMPOSITE
15
ELECTRODE
13 POLYMER MATERIAL

INTERNATIONAL SEARCH REPORT

International Application No PCT/JP91/00367

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int. Cl[5] H04R17/00

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC	H04R1/32, 17/00

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

Jitsuyo Shinan Koho 1963 - 1990
Kokai Jitsuyo Shinan Koho 1971 - 1990

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category *	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
X	JP, A, 1-120998 (Shimadzu Corp.), May 12, 1989 (12. 05. 89), (Family: none)	1-22
X	JP, A, 59-77799 (North American Philips Corp.), May 4, 1984 (04. 05. 84) & US, A, 4,518,889	1-22
A	JP, A, 61-76949 (Hitachi, Ltd.), April 19, 1986 (19. 04. 86), (Family: none)	1-22
A	JP, U, 59-183098 (Omron Corp.), December 6, 1984 (06. 12. 84), (Family: none)	1-22

* Special categories of cited documents: [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
May 23, 1991 (23. 05. 91)	June 10, 1991 (10. 06. 91)
International Searching Authority	**Signature of Authorized Officer**
Japanese Patent Office	