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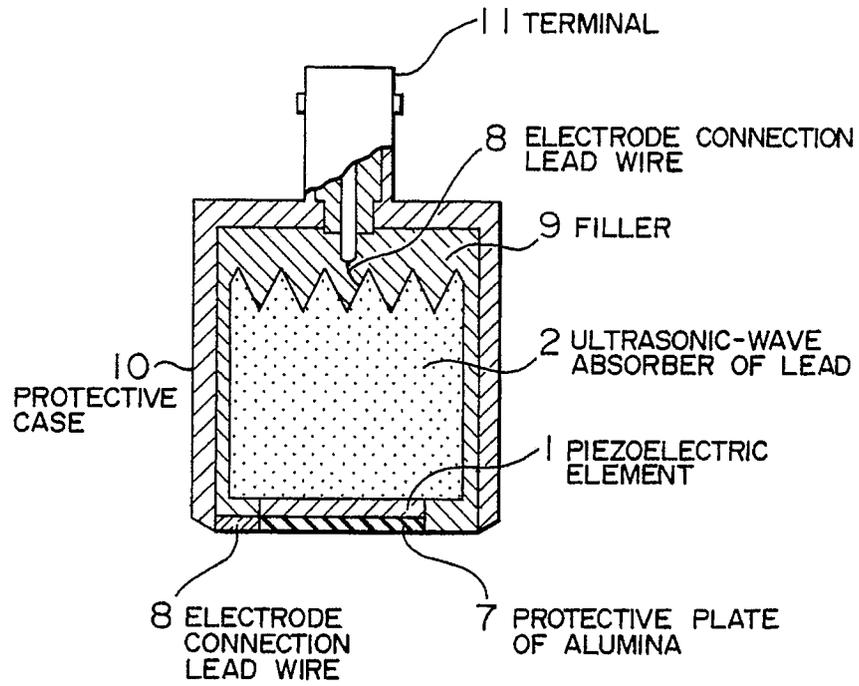
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ULTRASONIC PROBE AND METHOD OF PRODUCING THE SAME.

An ultrasonic probe characterized in that the junction surfaces of a piezo-electric element and an ultrasonic wave absorbing material are irradiated with corpuscular rays in a vacuum and are then press-adhered together. Therefore, the highly precise junction is accomplished without being exposed to high temperatures, and undesired reflection on the junction surfaces is prevented and reverberation is efficiently absorbed.

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FIG. 4



ULTRASONIC PROBE AND METHOD FOR MANUFACTURING THE SAME

TECHNICAL FIELD

This invention relates to the structure of a junction between a piezoelectric element and an ultrasonic-wave absorber in an ultrasonic probe and relates also to a method for manufacturing such an ultrasonic probe.

BACKGROUND ART

10 An ultrasonic-wave absorber and a piezoelectric element have hitherto been joined together by a method in which they are bonded by the use of an epoxy adhesive and also by a method in which a composite material prepared by mixing a heavy-metal filler with an epoxy resin is used as an ultrasonic-wave absorber, and a piezoelectric element is cast in the step of curing the ultrasonic-wave absorber.

The related art includes the disclosures of JP-A-60-58550 and JP-A-60-128358.

15 In the prior art described above, a seasoning deformation of the epoxy resin mixed with the heavy metal and that of the epoxy adhesive are not taken into consideration, and the prior art has thus had the problem that the acoustic characteristics of the ultrasonic probe are degraded with time. Also, because of a very large difference between the acoustic impedance of the epoxy adhesive and that of the piezoelectric element or that of the ultrasonic-wave absorber, the epoxy adhesive forms an acoustic boundary layer when the piezoelectric element and the ultrasonic-wave absorber are joined together by the use of the epoxy adhesive, and this results in reflection of the ultrasonic waves. Therefore, the prior art has had such another problem that the ultrasonic waves do not sufficiently propagate from the piezoelectric element toward the ultrasonic-wave absorber, and detrimental reverberation of the ultrasonic waves cannot be efficiently absorbed by the ultrasonic-wave absorber.

25 When a material having an acoustic impedance substantially equivalent to that of the piezoelectric element is employed as the ultrasonic-wave absorber, the ultrasonic waves generated from the piezoelectric element and propagating toward the ultrasonic-wave absorber are efficiently absorbed by the ultrasonic-wave absorber, so that the unnecessary reverberation would not occur. For that purpose, the piezoelectric element and the ultrasonic-wave absorber must be joined together without the use of the adhesive. This purpose will be attained by employing a metal material to form the ultrasonic-wave absorber and utilizing the joinability of the metal itself so as to join the ultrasonic-wave absorber to the piezoelectric element. As such a joining method, a method is commonly employed in which the metal is joined by heating it to a level higher than or close to its melting point. However, when such a joining method is employed so as to join the absorber to the piezoelectric element, the surface flatness of the piezoelectric element is lost due to a thermal strain attributable to a change in the temperature of the absorber, thereby giving rise to a degraded performance of the ultrasonic probe. Also, this thermal strain causes a seasoning deformation, with the result that the performance of the probe becomes unstable. Further, when this thermal strain is excessively large, breakage of the piezoelectric element tends to results, and the practical use of the ultrasonic probe will become utterly impossible.

40 The prior art has had the necessity for forming electrodes on the piezoelectric element, because the ultrasonic-wave absorber formed of an electrical insulator is used, or the ultrasonic-wave absorber formed of an electrical conductor is joined to the piezoelectric element by the use of the epoxy adhesive which is an electrical insulator. Also, the prior art has had such another problem that the strength of the joints between the electrodes and the piezoelectric element is weak, and the electrodes tend to be stripped off from the piezoelectric element during use.

DISCLOSURE OF INVENTION

50 It is an object of the present invention to provide the structure of an ultrasonic probe in which its piezoelectric element and its ultrasonic-wave absorber are joined together with a high strength, in which reverberation of ultrasonic waves can be efficiently absorbed, and in which the ultrasonic-wave absorber can be used as an electrode and to provide also a method for manufacturing such an ultrasonic probe.

According to the present invention which attains the above object, for the purpose of joining the piezoelectric element to the ultrasonic-wave absorber formed of a metal or formed by sintering metal

powders, their junction surfaces are irradiated with a particle beam in a vacuum, and they are then pressed against each other at a temperature lower than the Curie point of the oscillator.

Further, at the time of joining, a foil or film of an In alloy or an Fe alloy is inserted as an insert member, and the piezoelectric element and the ultrasonic-wave absorber are then pressed against each other while
5 irradiating their junction surfaces with the particle beam in the vacuum.

(Operation)

10 By irradiating the junction surface of the piezoelectric element and that of the ultrasonic-wave absorber, which is formed of the metal or formed by sintering the metal powders, with the particle beam in the vacuum, oils and fats, moisture, oxide films, etc. attaching to their junction surfaces are removed. As a result, hands of bond are exposed on the junction surfaces to provide highly active surfaces forming a firm junction, so that the piezoelectric element and the ultrasonic-wave absorber are firmly joined together when
15 brought into intimate contact with each other under application of a pressure.

Although high energy is injected into the irradiated surfaces according to this method, the energy injection is limited to the irradiated surfaces only. Therefore, when compared to the method of joining by heating the ultrasonic-wave absorber, the quantity of energy injected into the entire ultrasonic-wave absorber is very small. As a result, the thermal strain would hardly occur on the ultrasonic-wave absorber, and, therefore, the piezoelectric element maintains its surface flatness.
20

When the ultrasonic-wave absorber is such that it cannot be sufficiently joined to the piezoelectric element in spite of the irradiation with the particle beam, a firm junction can be attained when an insert member showing a good joinability to both the piezoelectric element and the ultrasonic-wave absorber is inserted into the junction surfaces. When the insert member is used, the insert member is subjected to
25 plastic deformation during application of the joining pressure, thereby improving the degree of intimate contact at the junction interface, so that a more firm and uniform junction can be provided.

Further, because both the ultrasonic-wave absorber and the insert member are electrical conductors, they can be used as electrodes.

30

BRIEF DESCRIPTION OF DRAWINGS

Fig. 1 is a front elevational view showing a method for establishing a metal-to-metal junction between a piezoelectric element and an ultrasonic-wave absorber.

35 Figs. 2 and 3 are longitudinal sectional views each showing the structure of the junction between the piezoelectric element and the ultrasonic-wave absorber formed of lead.

Fig. 4 is a longitudinal sectional view of an embodiment of the ultrasonic probe of the present invention.

40 BEST MODE FOR CARRYING OUT THE INVENTION

An embodiment of the present invention will now be described with reference to Fig. 1.

1 designates a piezoelectric element, 2 designates an ultrasonic-wave absorber formed of lead, 3 designates each of beam sources emitting an atom beam, and 4 designates each of pressure applying jigs.

45 First, the piezoelectric element 1 and the ultrasonic-wave absorber 2 are mounted on the pressure applying jigs 4, and the atmosphere is evacuated to a vacuum of 2×10^{-7} Torr. Then, argon gas is introduced into the beam sources 3 to set the pressure of the atmosphere at 4×10^{-4} Torr, and argon atom beams emitted from the beam sources 3 are directed toward and onto the junction surfaces of both the piezoelectric element and the ultrasonic-wave absorber 2 so as to remove contaminants and surface films.
50 Because the junction surfaces from which the contaminants and the surface films are removed have a very high degree of joinability, a metal-to-metal junction is easily formed when the junction surfaces are brought into intimate contact with each other by application of a pressure P at the room temperature.

In the illustrated embodiment, the piezoelectric element 1 and the ultrasonic-wave absorber 2 are directly joined. However, as shown in Fig. 2, a foil 5 of a soft metal which is liable to plastic deformation, such as, an In-Sn alloy, an In-Pb alloy or a Pb-Sn alloy may be used as an insert member. Also, as shown
55 in Fig. 3, a film 6 of a soft metal such as an In-Sn alloy, an In-Pb alloy or a Pb-Sn alloy or of an oxidation resistive metal such as gold or silver may be formed on the junction surface of the piezoelectric element 1 or the ultrasonic-wave absorber of lead 2 by means such as sputtering, plating or brazing, so as to realize a

firm junction without hardly abstracting propagation of ultrasonic waves.

Further, as shown in Table 1, any one of metals such as tungsten, zinc, iron, nickel, copper and indium having a large acoustic impedance (Column 1 in Table 1) can be used as the material of the ultrasonic-wave absorber 2, besides lead. Among those materials, a material having an acoustic impedance close to that of the piezoelectric element 1 and acting to greatly attenuate ultrasonic waves is most preferable. From this viewpoint, lead is most suitable for the purpose. However, the desired effect can be similarly exhibited even when any one of sintered bodies obtained by sintering powders or powder mixtures of metals having an acoustic impedance larger than that of the piezoelectric element 1 (Column 2 in Table 1) is used.

In the illustrated embodiment, an atom beam (neutron rays) is used as the particle beam. This is because the atom beam does not cause charge-up of an object to be irradiated and is therefore suitable for irradiation of an electrical insulator such as a ceramic oscillator. An ion beam can be also used as the particle beam. However, when the ion beam is used for irradiating an electrical insulator, it is necessary to simultaneously direct an electron shower so as to prevent charge-up.

Table 1

		Metal	Metal-powder sintered body
1	Acoustic impedance: large	W, Zn, Fe, Pb, Cu, Ni	W, W+Pb, Fe, W+In, Cu, Ni
2	Ultrasonic wave attenuation: large	Pb	W, W+Pb, W+In

The structure and operation of the ultrasonic probe manufactured according to the present invention will now be described with reference to Fig. 4. 1 designates the piezoelectric element, 2 designates the ultrasonic-wave absorber formed of lead, 7 designates a protective plate formed of alumina, 8 designates a lead wire connected to the electrode, 9 designates a filler, 10 designates a protective case, and 11 designates a terminal. The ultrasonic-wave absorber 2 formed of lead is an electrical conductor and can be used as an electrode for the piezoelectric element 1.

The operation will now be described. Ultrasonic pulses are generated when a pulse voltage from a pulse voltage generator (not shown) is applied to the piezoelectric element 1 through the terminal 11. The generated ultrasonic waves are injected through the protective plate 7 toward and into an object to be tested (not shown) for the purpose of ultrasonic nondestructive testing. Reverberation of the ultrasonic waves, which degrades both the accuracy of the ultrasonic nondestructive testing and the capability of fault or defect detection, is absorbed by the ultrasonic-wave absorber of lead 2 joined to the piezoelectric element 1.

Table 2 shows representative values of acoustic impedances of various materials. A composite material which consists of a heavy metal and a resin and whose typical example is a composite material consisting of minium and an epoxy resin has hitherto been widely employed as the material of the ultrasonic-wave absorber. However, in this case, the acoustic impedance is 0.5×10^6 g cm/s as shown in Table 2 and is for smaller than 2.3×10^6 g cm/s which is the typical value of the acoustic impedance of the piezoelectric element (the ceramic material having the composition of $(\text{Pb}(\text{Zr}, \text{Ti})\text{O}_3\text{-PbMo})$).

When the piezoelectric element and the ultrasonic-wave absorber have acoustic impedance Z_C and Z_D respectively, the acoustic reflectivity r at their junction interface is given by the following equation:

$$r = (Z_D - Z_C) / (Z_D + Z_C) \quad \dots \quad (1)$$

When, for example, the piezoelectric element is joined to the epoxy resin containing the minium, substitution of the value of the acoustic impedance shown in Table 2 into the equation (1) provides the result of $r=61\%$. Thus, it is proved that more than the half of the acoustic waves are reflected at the acoustic waves do not efficiently propagate toward the ultrasonic-wave absorber.

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Table 2

Material	Acoustic impedance ($\times 10^6$ g cm/s)
Piezoelectric element ($\text{Pb}(\text{Zr}, \text{Ti})\text{O}_3$ - PbMo)	2.3
Lead	2.5
Zinc	3.0
Tungsten	10.4
Iron	4.5
Copper	4.2
Nickel	5.0
Minium 70 vol % - epoxy resin 30 vol %	0.5
Epoxy resin	0.3

On the other hand, when lead is used as the material of the ultrasonic-wave absorber, $r=4\%$ is derived from the equation (1) in view of the acoustic impedance value shown in Table 2. Thus, reflection of the ultrasonic waves at the junction interface is minimized, so that the ultrasonic waves can be efficiently propagated toward the ultrasonic-wave absorber. The illustrated embodiment exhibits the effect that unnecessary reverberation of ultrasonic waves can be extinguished within a very short period of time.

It is known that the less the reverberation of ultrasonic waves, the performance of the ultrasonic probe is higher. When the oscillator, the insert member and the ultrasonic-wave absorber have acoustic impedances Z_E , Z_i and Z_D respectively, the order of the performance of the ultrasonic probe dependent on the relative amounts of the acoustic impedances is as follows:

1. $Z_E = Z_i = Z_D$
2. $Z_E > Z_i = Z_D$
3. $Z_E > Z_i > Z_D$
4. $Z_E > Z_i < Z_D$

In the case of the sintered body obtained by sintering metal powders, the relation $Z_i = Z_D$ or $Z_i > Z_D$ can

be easily provided, because the acoustic impedance can be controlled over a wide range by suitably selecting the ratio of the mixed materials. Therefore, when the metal-powder sintered body is used as the ultrasonic-wave absorber, the probe exhibiting high performance can be easily manufactured.

Further, because the insert member is a solid, its thickness can be easily controlled. Therefore, when the thickness of the insert member is selected to be equal to $1/4 \lambda$ (λ : the wavelength of ultrasonic waves), an acoustic matching layer can be formed, so that the reverberation of the ultrasonic waves can be efficiently propagated toward the ultrasonic-wave absorber.

10 INDUSTRIAL APPLICABILITY

An ultrasonic probe in which the acoustic wave reverberation time does not change over a long period of time can be provided, because a metal material having a property free from any secular variation can be used to form its ultrasonic-wave absorber. Also, because a metal having a large acoustic impedance can be used as the material of the ultrasonic-wave absorber, reflection of the ultrasonic wave at the interface between the piezoelectric element and the ultrasonic wave absorber can be minimized.

Further, because the oscillator and the ultrasonic-wave absorber are joined together at the room temperature in the illustrated embodiment, no residual thermal strain attributable to joining occurs. The coefficient of linear expansion of the ultrasonic-wave absorber is not generally equal to that of the oscillator. Therefore, when they are joined at a high temperature, problems including a variation of the piezoelectric characteristic of the oscillator due to a residual thermal strain and degradation of the surface flatness of the oscillator after cooling arise, resulting sometimes in breakage of the oscillator, strip-off at the junction part, etc. These problems do not arise in the illustrated embodiment in which joining is made at the room temperature. However, when temperature range where a variation of the piezoelectric characteristic or a variation of the surface flatness of the oscillator falls in an allowable range, the yield strength of the ultrasonic-wave absorber or the insert member is lowered to increase of plastic deformability. Thus, heating is effective for promoting the intimate contact at the junction, thereby improving both the junction strength and the reliability.

Electrodes for the piezoelectric element have hitherto been formed by brazing. According to the present invention, the ultrasonic-wave absorber formed of a metal can be used as one of the electrodes. Thus, it is merely necessary to form the other electrode on one surface only of the piezoelectric element, thereby simplifying the steps of manufacturing the piezoelectric element.

35 Claims

1. A method for manufacturing an ultrasonic probe characterized by irradiating junction surfaces of a piezoelectric element and an ultrasonic-wave absorber with a particle beam in a vacuum and then pressing the two junction surfaces against each other by application of a pressure.
2. An ultrasonic probe characterized in that an ultrasonic-wave absorber joined to a piezoelectric element is used as an electrode.
3. A method for manufacturing an ultrasonic probe as claimed in Claim 2, characterized in that a foil of an In alloy or a Pb alloy is inserted between the piezoelectric element and the ultrasonic-wave absorber.

Amended Claims

1. A method for manufacturing an ultrasonic probe characterized by irradiating junction surfaces of a piezo-electric element and an ultrasonic-wave absorber with a particle beam in a vacuum and then pressing the two junction surfaces against each other by application of a pressure.
2. A method for manufacturing an ultrasonic probe as claimed in Claim 1, wherein said ultrasonic-wave absorber is either one of lead, zinc, iron, nickel, copper and indium, or an alloy thereof, or sintering powders of the metal among them.
3. A method for manufacturing an ultrasonic probe as claimed in Claim 1, wherein said ultrasonic-wave absorber is lead.

4. A method for manufacturing an ultrasonic probe as claimed in Claim 1, characterized in that a foil of an In alloy or a Pb alloy is inserted between said piezo-electric element and said ultrasonic-wave absorber.

5. A method for manufacturing an ultrasonic probe as claimed in Claim 1, wherein at least one of said junction surfaces of said piezo-electric element and said ultrasonic-wave absorber is formed with a layer of an In-Sn alloy, an In-Pb alloy, gold, or silver.

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FIG. 1

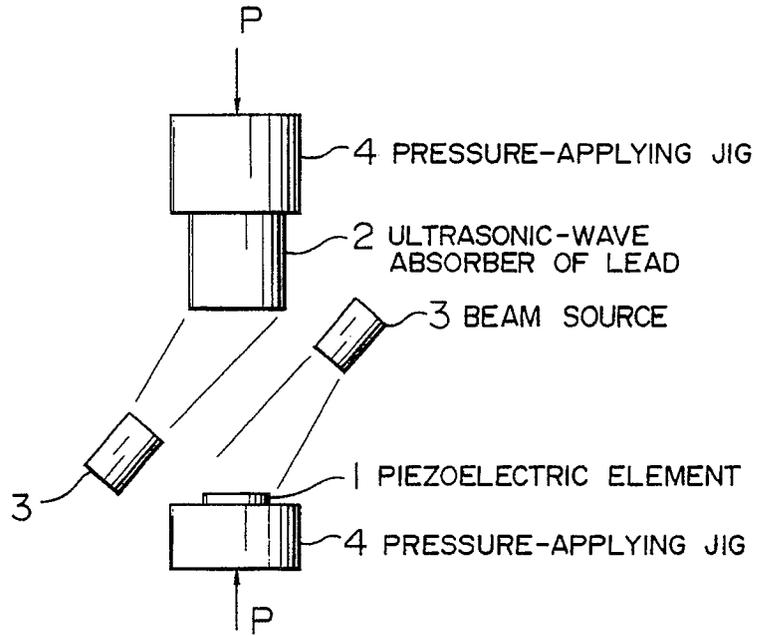


FIG. 2

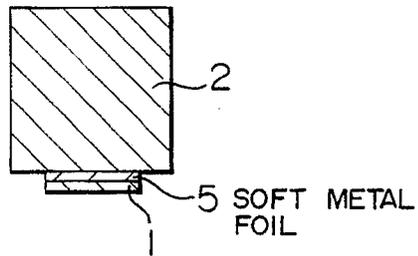
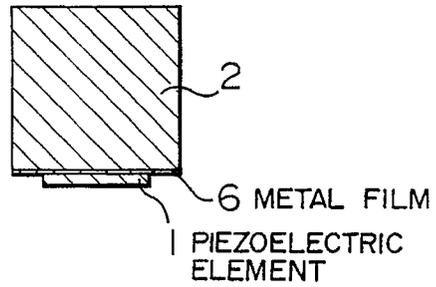
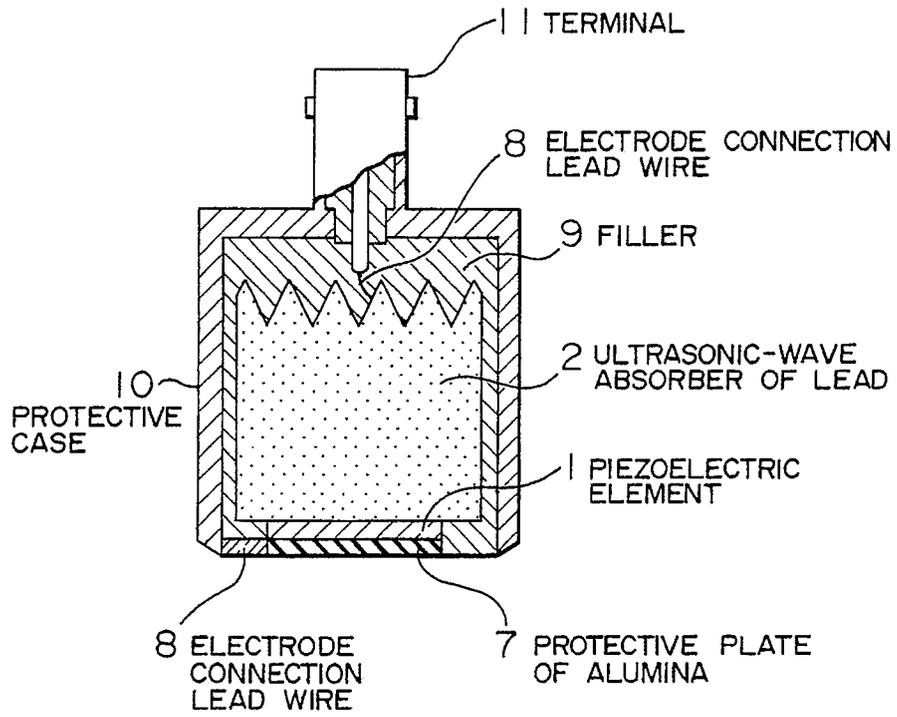


FIG. 3



F I G. 4



INTERNATIONAL SEARCH REPORT

International Application No PCT/JP90/00605

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	H04R17/00			
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched ⁸				
Jitsuyo Shinan Koho	1971 - 1989			
Kokai Jitsuyo Shinan Koho	1971 - 1989			
III. DOCUMENTS CONSIDERED TO BE RELEVANT ⁹				
Category ⁹	Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³		
A	JP, A, 63-255657 (Ishikawajima-Harima Heavy Industries Co., Ltd.), 21 October 1988 (21. 10. 88), (Family: none)	1		
X	JP, B2, 59-12079 (Toray Industries, Inc.), 21 March 1984 (21. 03. 84), Line 38, column 9 to line 32, column 10; Fig. 8, (Family: none)	2, 3		
X	JP, A, 55-75646 (Mitsubishi Electric Corp.), 7 June 1980 (07. 06. 80), (Family: none)	2, 3		
<p>¹⁰ Special categories of cited documents:</p> <table style="width: 100%; border: none;"> <tr> <td style="width: 50%; border: none;"> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> </td> <td style="width: 50%; border: none;"> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"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</p> <p>"&" document member of the same patent family</p> </td> </tr> </table>			<p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p>	<p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"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</p> <p>"&" document member of the same patent family</p>
<p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p>	<p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"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</p> <p>"&" document member of the same patent family</p>			
IV. CERTIFICATION				
Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report			
July 13, 1990 (13. 07. 90)	July 30, 1990 (30. 07. 90)			
International Searching Authority	Signature of Authorized Officer			
Japanese Patent Office				