Oct. 30, 1956 C. K. GRAVLEY 2,768,421

METHOD OF MAKING CIRCUIT CONNECTIONS TO A TRANSDUCER UNIT

Filed May 17, 1952 2 Sheets-Sheet 1

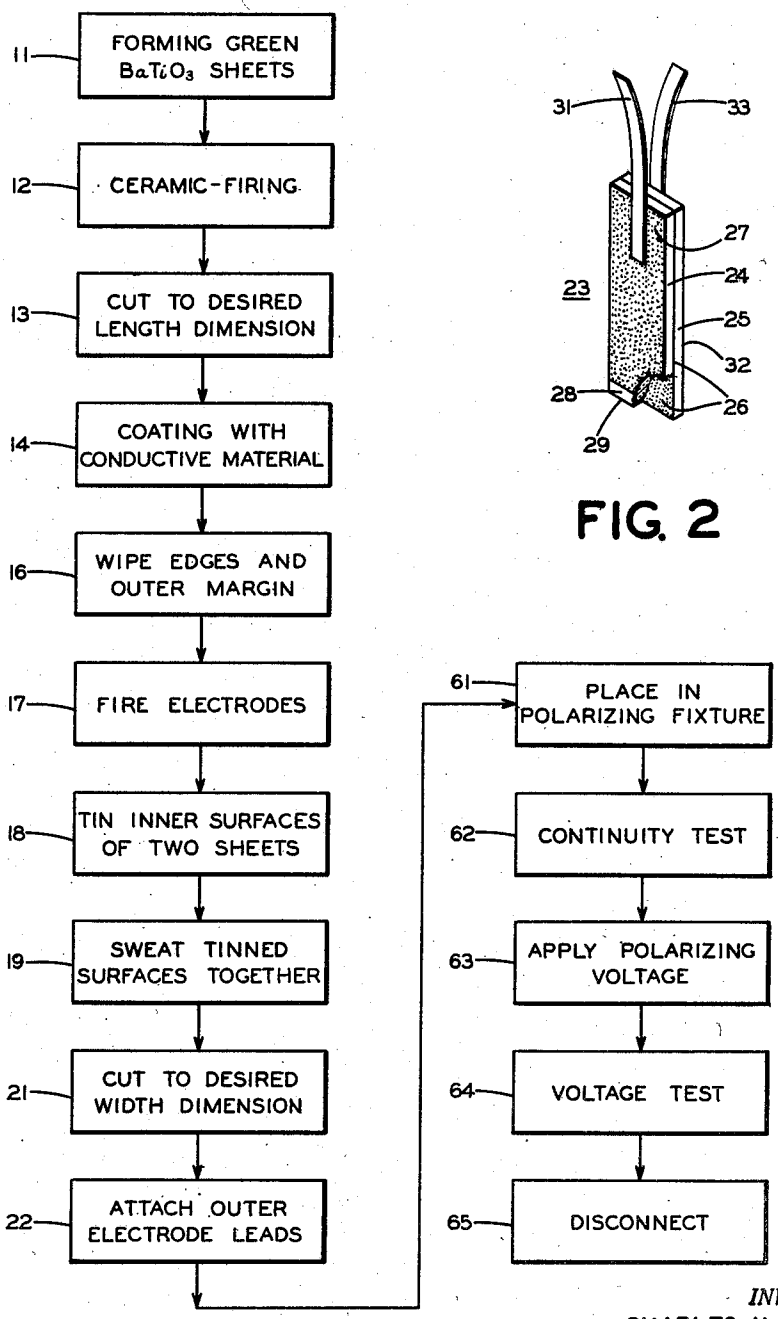


FIG. 1

FIG. 2

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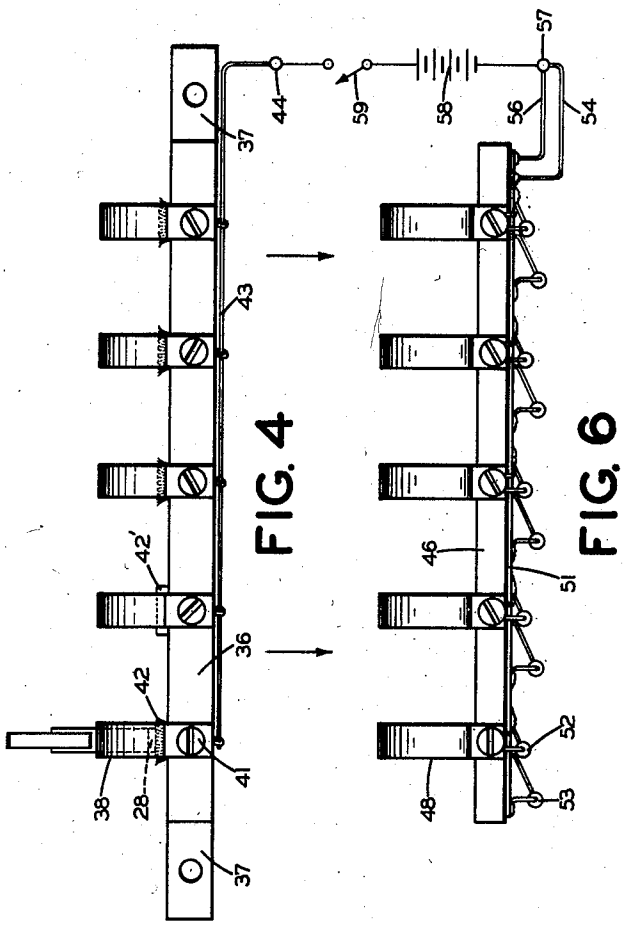


FIG. 4

FIG. 6

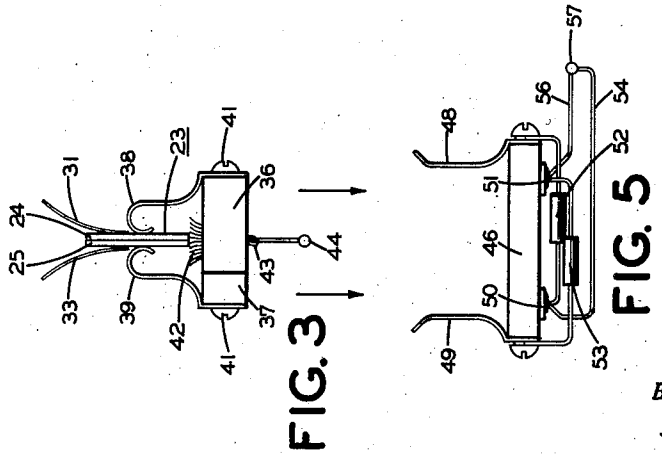


FIG. 3

FIG. 5

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2,768,421

METHOD OF MAKING CIRCUIT CONNECTIONS TO A TRANSDUCER UNIT

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Application May 17, 1952, Serial No. 288,566

4 Claims. (Cl. 29—25.35)

This invention relates to a method of making electrical circuit connections to a transducer unit of the type having a plurality of thin, electromechanically responsive plates assembled face to face, and particularly to methods of making circuit connections with such a transducer unit to an interior electrode which is not supplied with conductive lead wires extending outwardly from the interior electrode.

In the field of electromechanical transducers utilizing electromechanically responsive dielectric materials, a type of transducer unit having a plurality of thin plates of such a material assembled face to face has proved to be of great practical utility. Such a transducer unit may be characterized as a sandwich unit, since the plates of piezoelectric or other electromechanically sensitive material are placed together face to face, usually with an electrode or electrodes therebetween. As is well known in the art, these sandwich units may be made to have an electromechanical response in a flexing mode. Thus two plates of piezoelectric material, such as Rochelle salt or ammonium dihydrogen phosphate, having the proper crystallographic orientations, may be assembled in a sandwich unit having a response in a bending mode. A modification of the crystallographic orientations of the plates produces a transducer unit having a response in a twisting mode.

In addition to the bender and twister units made of single-crystalline plates, bender transducer units may be made of polycrystalline ceramic plates. Transducers incorporating ceramic bodies of polycrystalline barium titanate material are disclosed and claimed in the patent to R. B. Gray No. 2,486,560, and ceramic transducer plates of such material are suitable for inclusion in bender transducer units. Other titanate-type electromechanically responsive materials of modified or different compositions are operative in such transducer units.

Polycrystalline dielectric bodies of the titanate-type materials respond to the application of an electrostatic field by developing mechanical strains, so that these materials are electromechanically responsive without any special treatment. However, their usefulness in most electromechanical transducer arrangements is based upon the fact that a suitable conditioning treatment brings about an electromechanical sensitivity which is both linear and of high magnitude whether transducing is from electrical to mechanical energy or vice versa. The conditioning treatment ordinarily involves the application of a high unidirectional electrical potential across the polycrystalline body and is known as a polarizing operation. Such a treatment is described in the aforementioned Patent No. 2,486,560. The body so treated acquires a large so-called electrostatic polarization, which, after removal of the polarizing voltage, may leave a large remanent polarization, most of which persists for an indefinite period of time unless certain limits of temperature or of applied electrostatic signal field strength of opposite polarity are exceeded in the material. In accordance with one theory, this so-called polarization of the material is the result of non-random directional changes induced by the applied unidirectional potential in a spontaneous polarization already present at certain temperatures in small, randomly oriented crystalline domains in the material. Whatever the correct explanation may be, the conditioning treatment to induce high electromechanical sensitivity is an important step in the manufacture of titanate-type transducer units.

The provision of inner electrodes between the dielectric plates of a sandwich transducer unit and the fastening together of the elements of the sandwich unit have presented difficult manufacturing problems. Techniques have been developed for providing thin electrodes between the plates and for cementing the electroded plates firmly together. In the case of polycrystalline plates soldering techniques may be used for fastening the electroded surfaces together. The insertion of a mechanically strong conductive lead wire or strip between the plates and extending outwardly from the region therebetween brings about additional problems of bonding the plates together, often introducing undesirable elastic properties in the assembled unit and complicating fabrication of the unit and handling of the parts during fabrication and thereafter.

If satisfactory electrical connections could be made to the inner electrode or electrodes without using a lead wire or strip anchored between the plates the advantages would be obvious. With the polycrystalline transducer materials, in particular, connections to the interior electrode or electrodes in many cases may be omitted during use as a transducer, so that it is necessary to make such connections only during the polarizing operation mentioned hereinabove. In this case, particularly, where the connection to the inner electrode may be considered a temporary one, there would be obvious advantages in making this connection without necessitating the inclusion of a heavy conductive structure between the plates.

Accordingly it is an object of this invention to provide a new and improved method of making electrical circuit connections to a transducer unit having a plurality of thin plates assembled face to face which avoids one or more of the disadvantages of the methods known to the prior art.

It is another object of this invention to provide a new and improved method of making circuit connections to a sandwich type transducer unit without the provision of a bulky or mechanically fragile lead conductor between the plates of the sandwich unit.

It is a further object of this invention to provide a new and improved method of making circuit connections to a transducer unit which has a plurality of titanate-type plates assembled face to face, particularly during the prepolarizing operation.

In accordance with the invention, the method of making electrical circuit connections to a transducer unit having a plurality of thin, electromechanically responsive plates assembled face to face comprises providing the transducer assembly with an inner electrode between two of the plates extending to one edge of the assembly and also with outer electrode means, adjacent to at least one of the two exposed surfaces of the multiplate assembly, having a margin separating the outer electrode means from the aforementioned one edge of the assembly. The method further comprises pressing that one edge of the assembly against yieldable conducting means to effect electrical contact of the inner electrode to the conducting means while the outer electrode means is insulated therefrom by the aforesaid margin, and completing the desired circuit connections across the conduct-

ing means and at least a portion of the outer electrode means.

For a better understanding of the present invention, together with other and further objects thereof, reference is had to the following description taken in connection with the accompanying drawings, and its scope will be pointed out in the appended claims.

In the drawings,

Fig. 1 is a flow sheet or block diagram representing the preparatory operations and the further steps used in carrying out one embodiment of the method of the invention;

Fig. 2 is a perspective view, partially cut away, of a transducer assembly suitable for use in accordance with the method of the invention;

Figs. 3 and 4 are end and side elevations respectively of a receptacle which holds transducer assemblies of the type illustrated in Fig. 2 and which is useful in carrying out the method of the invention; and

Figs. 5 and 6 are corresponding end and side elevations respectively of a fixture for receiving the receptacle of Figs. 3 and 4 in accordance with one embodiment of the method of the invention.

Referring now to Fig. 1, there are represented in block diagram or flow sheet form the several steps involved in preparing for and carrying out an embodiment of the present invention involving a transducer unit having a plurality of thin, electro-mechanicaly responsive plates assembled face to face. More particularly the invention is described in connection with a transducer unit having two thin plates of titanate-type polycrystalline material. In a typical unit each plate of the two plate unit may have identical thicknesses, for example in the range of 0.007 to 0.025 inch thick.

As represented in Fig. 1, the material for these plates is formed in sheets of raw or green polycrystalline barium titanate, this step being indicated at **11** in Fig. 1. Such sheets having satisfactory flatness may be formed by dipping a combustible, flat backing sheet in a suspension of powdered barium titanate in accordance with the method disclosed and claimed in Patent No. 2,554,327, issued May 22, 1951, on an application filed June 12, 1948, by the present applicant and assigned to the same assignee as the present invention. After a green polycrystalline sheet of the required thickness has been formed on each side of the backing sheet, they are sprinkled with a refractory powder to prevent sticking, placed in stacks, and the stacks subjected to a ceramic-firing operation, as represented at **12** in Fig. 1.

Each side of each backing sheet used in the forming operation just described, provides one thin fired ceramic sheet, which conveniently may be about 2 to 2¾ inches on a side. In the operation represented at **13** in Fig. 1 these sheets are placed in piles, their edges are trimmed, and one-lateral dimension of all sheets in a pile is cut to the length of the thin plates needed for the transducer units to be made. If this length is ¾ inch, for example, two or three strips having this desired dimension may be obtained from each fired sheet. Following this first cutting operation the individual strips are separated with a thin instrument and cleaned, preferably on a burnishing wheel.

In the next operation the strips are supplied with electrodes, after which the strips may be fastened together in pairs. The electrodes may be of metal foil cemented to the strips, two electroded surfaces later being cemented together to form a sandwich. However, it is preferred to dip the strips in a suspension of a powder containing metallic silver particles and a vitreous binder in a suitable vehicle, such as toluol, preparatory to the formation of electrodes on the major surfaces of the strips. To prevent short-circuiting of the electrodes the edge surfaces are wiped clean of the conductive deposit. Furthermore, for reasons which will appear hereinbelow, on each strip a margin near one edge of one major surface—that surface which is to become the outer surface of the sandwich unit—also is wiped clean. Alternatively, instead of coating the entire unit and wiping or otherwise cleaning the edges and the margin, the latter surfaces may be masked prior to application of the conductive material. Thereafter the electrode coat is fired at about 1300° F., leaving an adherent conductive coating on both faces of each strip with a margin on the outer face near one edge. If necessary any conductive material remaining on the edges and on the last-mentioned margin may be removed by grinding. These steps of coating with the unfired conductive material, wiping the edges and the outer margin to prevent short-circuiting, and firing the electrodes are represented in Fig. 1 at **14**, **16**, and **17** respectively.

To assemble the two-plate transducer units the outer surface of each electroded strip is masked and the strips are dipped in a solder bath to tin the electroded inner surface. The tinned surfaces of two such sheets then are placed face to face and the assembly heated until the tinned surfaces fuse, thus forming a sandwich of two strips with an electrode between them. The two strips are arranged for assembly so that the margin on the outer surface of each strip is next to the same edge of the assembly. The tinning operation and the step of sweating the two tinned surfaces together are represented at **18** and **19** respectively in Fig. 1.

The operations already described produce sandwiches which, for the dimensions given by way of example, are ¾ inch by about 2 to 2½ inches in lateral size. Unelectroded margins are provided near one of the longer edges on both major faces. These strips then are separated into the desired transducer units by making repeated saw cuts parallel to the smaller dimension of the sheets and separated by the desired width dimension of the transducer units. If the width dimension desired is 3/32 inch, for example, the individual transducer units have major faces ¾ inch long and 3/32 inch wide with unelectroded margins on each outer electrode near one end of each unit. At this stage it is convenient to affix conductive leads to the outer electrodes by soldering, if such leads are to be required, since the heating of the plates during the soldering operation might destroy remanent polarization if attempted after the prepolarizing operation. The steps of cutting the units to the desired width dimension and of attaching the outer electrode leads are represented at **21** and **22** respectively in Fig. 1.

A perspective view of the unit obtained by the steps described hereinabove appears in Fig. 2. The transducer unit **23** has two thin plates of titanate-type polycrystalline material **24** and **25** assembled face to face, with the common tinned electrode **26** therebetween as seen in the cut-away portion of Fig. 2. The plate **24** has an electrode **27** covering its outer surface except for a margin **28** near one edge **29** of the unit. A conductive lead in the form of a copper strip **31** is soldered to the electrode **27** near the other end of the assembly. The plate **25** likewise has an electrode **32**, not visible in Fig. 2, to which a lead strip **33** is attached in a similar manner. It will be understood that the margin **28**, near the edge **29** of the unit, also is present at the lower end of the electrode **32**.

Thus it will appear that a transducer assembly has been provided, as shown in Fig. 2, having a plurality of plates, specifically two thin, electromechanically responsive plates **24** and **25**, assembled face to face. This assembly is provided with an inner electrode **26** between the two plates extending to one edge **29** of the assembly and with outer electrode means, adjacent to at least one of the two exposed surfaces of the multiplate assembly, having a margin **28** separating this outer electrode means from the one edge **29** of the assembly. This outer electrode means includes the two outer electrodes **27** and **32**, each of which has the margin **28** separating it from the edge **29**. The lead conductors **31** and **33** are conductively affixed to the two outer electrodes **27** and **32** only for

making eventual permanent electrical connections to the transducing unit.

In carrying out the method of making electrical circuit connections to the transducer unit in accordance with the present invention, the edge **29** of the assembly is pressed against yieldable conducting means to effect electrical contact of the inner electrode **26** at the edge **29** to the yieldable conducting means while the outer means is insulated from the conducting means by the margin **28**. In a preferred embodiment of this stage of the method of the invention, the apparatus illustrated in Figs. 3–6 may be used. This apparatus serves as a fixture for making the circuit connections, and in the particular case described serves as a polarizing fixture for prepolarizing the titanate-type material making up the plates **27** and **32** in the transducer unit **23**.

Referring to Figs. 3 and 4, there is illustrated in end and front elevation respectively a receptacle for receiving a number of the units **23**. The illustrated arrangement holds five such units, but it will be understood that a longer receptacle could be made to hold many more units. The receptacle has a base **36** of a non-conductive material, such as a fabric block impregnated with a phenolic resin. The base **36** is provided with extensions **37**, **37** on its ends for ease of handling. Six pairs of Phosphor bronze spring contacts, such as the pair **38**, **39**, are spaced along the length of the base **36**. The contacts of each pair are held individually at the bottom thereof by screws **41**, **41** in opposite sides of the base **36**. The upper portions of the contacts are bent over to provide curving faces, the opposed faces of the curved contacts being biased toward each other by the resilience of the metal. The shape of the curved upper portions of the contacts **38** and **39** preferably is such as to tend to urge a member inserted therebetween downward toward the base **36**.

Directly beneath the region of mutual contact between the pair of contacts **38**, **39** there is affixed to the base the yieldable conducting means **42**. A yieldable conducting means is provided beneath each pair of contacts, and these conducting means are interconnected by a wire **43**, which conveniently may run beneath the base **36** to a terminal **44** at one end thereof. The conducting means may have the form of a yieldable body of rubber-like material having a conductive surface region, and such a yieldable body is illustrated in Fig. 4 at **42'** in association with the second pair of spring contacts. The body **42'** may be a soft, natural rubber body pigmented throughout the body, including the upper surface region thereof, with acetylene black, which is ground into the rubber latex during the formation of the body **42**. Alternatively the upper surface region of the soft rubber-like body **42'** may be made conductive by application of a thin tin or silver foil. In another form, the conducting means comprises at least one thin, resilient metallic member adapted to resist downward pressure. In the form illustrated at **42** in Fig. 3, the conducting means is made up of a large number of thin, stiff, conductive metal filaments having the shape of a small brush. It will be evident that the choice of suitable yieldable conducting means will depend on such factors as the pressure which can be exerted against the transducer assembly without breakage, the nature of the inner electrode **26**, and the conductivity of the electrical contact required to be made with the inner electrode. If the inner electrode is of metal foil, it may protrude very slightly here and there at the edge **29** of the unit, making possible good contact with a rubber-like body under small pressures. Using electrodes formed of discrete particles removed from the edge **29** by wiping or grinding, the use of thin wires to make contact with the inner electrode permits even a slight occasional penetration of the space between the strips **27** and **32** and has been found to provide a satisfactory electrical contact.

A fixture, adapted to receive the receptacle illustrated in Figs. 3 and 4, is shown in end and side elevations in Figs. 5 and 6 respectively. The main portion of this fixture is a large block **46**, which may be of the same nonconductive material as that of the base **36** in the receptacle described above. Affixed to opposite edges of the block **46** are pairs of Phosphor bronze spring contacts **48**, **49**, each pair being separated by a distance somewhat smaller than the distance between the heads of the screws **41**, **41** holding each pair of contacts **38**, **39** of the receptacle. Affixed to the bottom of the block **46** are two conductive straps **50**, **51**. Each spring member **48** and **49** is connected through a resistor **52** or **53** to one of the straps **50** or **51**. Each of these resistors may have a resistance of the order of 10 megohms. The straps **50** and **51** are connected by wires **54** and **56** to a common terminal **57**. In carrying out the method of the invention, the contacts **38** and **39** are spread apart and the transducer unit assembly **23** inserted therebetween with the leads **31**, **33** extending upward, as seen in Figs. 3 and 4. The assembly **23** is urged downward during the insertion. When the contacts **38** and **39** are released against the sides of the unit **23**, the one edge **29** of that unit is pressed against the yieldable conducting means **42** to effect electrical contact of the inner electrode **26** to the conducting means while the outer electrodes **27** and **32** and their lead conductors **31** and **33** are insulated from the conducting means **42** by the margin **28**.

After a transducer has been placed between each pair of contacts, the receptacle shown in Figs. 3 and 4 is picked up by the base portions **37**, **37** and inserted against the upper surface of the strip **46** of the fixture shown in Figs. 5 and 6. This operation is represented in the drawings by the vertical arrows below Figs. 3 and 4. In this position the spring members **48** and **49** of the fixture press against the screws **41**, **41** holding the respective contacts **38** and **39** of the corresponding pair of contacts in the receptacle. Likewise each pair of contacts in the receptacle is received conductively by a pair of spring members in the lower fixture. After this operation the air surrounding the entire fixture may be heated as desired, or the entire fixture may be immersed in an insulating oil at room temperature or at any desired temperature. With the receptacle inserted to make the contacts as described, circuit connections can be completed across the yieldable conducting means **42** and at least a portion of the outer electrode means of the unit **23**; this portion of the outer electrode means may be one, and ordinarily both, of the outer electrodes **27** and **32**. In the present example it will be understood that the electrical contact thus effected and the circuit connections thus completed are temporary, the leads **31** and **33** being provided on each unit **23** for permanent electrical connections during use after prepolarization. However, it also will be understood that similar electrical connections could be made during continuous and extended use of the unit **23** if such use necessitated connections to the inner electrode **26**.

For the prepolarizing operation the temporary circuit connections across the conducting means **42** and at least a portion of the outer electrode means, more specifically at least one and preferably both of the outer electrodes **27** and **32**, are completed by connecting a source **58** of a unidirectional electrical potential through a switch **59** across the terminals **44** and **57** for a predetermined period of time to provide remanent polarization of all of the polycrystalline material adjacent to and beneath those portions of the outer electrode means which are wired to the terminal **57**. It will be seen that both of the outer electrodes **27** and **32** are connected in parallel through the contacts **38**, **39**, to the screws **41**, **41**, the spring members **48**, **49**, the resistors **52**, **53**, the straps **50**, **51**, and the wires **54**, **56**, so that the polarizing voltage is applied across both of the plates **24** and **25** of the unit **23**, but in opposite thickness directions in the two plates.

The placing of the unit **23** and similar units in the

receptacle of Figs. 3 and 4 and the insertion of the receptacle in the fixture of Figs. 5 and 6 is indicated at **61** in Fig. 1, which calls for placing the transducer units in the polarizing fixture. Moreover, at this point it has been found desirable to test the apparatus for electrical continuity before, and sometimes after, the polarizing voltage is applied. The continuity test is represented in Fig. 1 at **62**. It may be carried out by connecting an A.-C. voltage source, not shown, between the terminal **44** and a test prod. The prod then is drawn across the fixture so as to contact each of the spring elements **48** and **49** in succession. The reactive current flowing through the corresponding plate of each unit **23** to this test connection is indicated by conventional means, and the contacts are moved to improve the connections or the transducer unit involved is rejected if an abnormally low current is indicated. This test may be repeated after the polarizing voltage has been applied, if desired.

When continuity thus has been assured, the switch **59** is closed to apply the polarizing voltage, as represented at **63** in Fig. 1. A suitable polarizing voltage for barium titanate elements may be about 20 kilovolts per inch; thus for plates 0.020 inch thick the polarizing voltage may be about 400 volts. As the capacitance of each plate **27** and **32** is charged through the associated resistor **52** or **53**, the voltage across the plate may drop to the neighborhood of 100 volts. After 10 or 15 minutes, however, the polarizing operation will have been completed and the full voltage from the source **58** should be found across each plate of each transducer unit. A voltage test, indicated at **64** in Fig. 1, preferably is carried out at this time. The voltage test may be made by connecting one side of a volt meter to the terminial **44** and the other side to a test prod. This test prod is run across the fixture so as to touch each contact **38** and **39** in quick succession. The volt meter reading remains at 400 volts almost continuously if this test operation is carried out quickly on an apparatus in which each unit **23** has been polarized successfully. However, in case of a low resistance or short circuit within a unit **23**, some or most of the polarizing voltage will be dropped across one of the resistors **52** or **53**, and the volt meter reading will drop as the prod is run across the contact touching the defective unit.

After any transducer unit which is found defective in the voltage test is marked for rejection, the switch **59** is opened, the receptacle holding the transducer units is lifted out of the lower part of the fixture and the transducer units are taken out of the receptacle. This last disconnecting operation is indicated at **65** in Fig. 1.

While there has been described what at present in considered to be the preferred embodiment of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention. It is aimed therefore in the appended claims to cover all such changes and modifications which fall within the true spirit and scope of the invention.

What is claimed is:

1. The method of making electrical circuit connections to a transducer unit having a plurality of thin plates of titanate-type polycrystalline material assembled face to face, comprising: providing said transducer assembly with an inner electrode between two of said plates extending to one edge of said assembly and with outer electrode means, adjacent to at least one of the two exposed surfaces of said multiplate assembly, having a margin separating said outer electrode means from said one edge of said assembly; pressing said one edge of said assembly against yieldable conducting means to effect electrical contact of said inner electrode with said conducting means while said outer electrode means is insulated therefrom by said margin; and connecting a source of a unidirectional electrical potential across said conducting means and at least a portion of said outer electrode means for a predetermined period of time to provide remanent polarization of said polycrystalline material adjacent to said portion of said outer electrode means.

2. The method of polarizing a transducer unit having two thin plates of titanate-type polycrystalline material assembled face to face, comprising: providing said transducer assembly with an inner electrode between said two plates extending to one edge of said assembly and with outer electrodes, adjacent to the two exposed surfaces of said two plates, having margins separating each of said outer electrodes from said one edge of said assembly; pressing said one edge of said assembly against yieldable conducting means to effect electrical contact of said inner electrode with said conducting means while said outer electrodes are insulated therefrom by said margins; and connecting a source of a unidirectional electrical potential across said outer electrodes, connected in parallel, and said conducting means for a predetermined period of time to provide remanent polarization of said polycrystalline material in opposite directions in said two plates.

3. The method of making electrical circuit connections to a transducer unit having a plurality of thin, electromechanically responsive plates assembled face to face, comprising: providing said transducer assembly with an inner electrode between two of said plates extending to one edge of said assembly and with outer electrode means, adjacent to at least one of the two exposed surfaces of said multiplate assembly, having a margin separating said outer electrode means from said one edge of said assembly; pressing said one edge of said assembly against a yieldable body of rubber-like material having a conductive surface region to effect electrical contact of said inner electrode with said surface region while said outer electrode means is insulated therefrom by said region; and completing said circuit connections between said yieldable body and at least a portion of said outer electrode means.

4. The method of making electrical circuit connections to a transducer unit having a plurality of thin, electromechanically responsive plates assembled face to face, comprising: providing said transducer assembly with an inner electrode between two of said plates extending to one edge of said assembly and with outer electrode means, adjacent to at least one of the two exposed surfaces of said multiplate assembly, having a margin separating said outer electrode means from said one edge of said assembly; pressing said one edge of said assembly against yieldable conducting means comprising at least one thin, resilient metallic member to effect electrical contact of said inner electrode with said conducting means while said outer electrode means is insulated therefrom by said margin; and completing said circuit connections across said conducting means and at least a portion of said outer electrode means.

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