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THE DESIGN AND CONSTRUCTION OF PIEZO-CERAMIC STACK ASSEMBLIES

BY

C. M. HUBBARD

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ADMIRALTY RESEARCH LABORATORY
TEDDINGTON MIDDLESEX.

ADMIRALTY RESEARCH LABORATORY, TEDDINGTON, MIDDLESEX

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The Design and Construction of Piezo-ceramic Stack Assemblies

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ABSTRACT

This note describes the techniques at present in use at A.R.L. for assembling and consolidating piezo-ceramic disc stacks for hydrophones and projectors. Dimpled metal electrodes are used for electrical contact and glue thickness control. It is primarily intended as a guide for those engaged in the work but some comments on design principles and general glueing practice are included.

INTRODUCTION

Stack type hydrophone construction has been in use at A.R.L. since 1954 and the design considerations and construction methods then in use have been described in previous reports.

These methods did not always produce reliable results and with the adoption of stack construction for projector units, demanding high strength joints, many changes of technique have been made over the years.

This note records the present (1962) practice in design and assembly procedure and is intended as a guide to those engaged in the work. It is not suggested that the methods described are the only satisfactory way of achieving high-strength reliable joints, but so many pitfalls are possible to those without experience of this work that some kind of written standard procedure has become necessary.

It is hoped that if this note is read by those who have evolved their own techniques, its didactic flavour will be forgiven.

The glue referred to throughout is Epophen 841 with Hardener 219 manufactured by Lester Lovell Ltd., Southampton but most of the general observations are valid for other epoxy resin materials.

2. THE DESIGN OF STACKS FOR TRANSDUCERS AND HYDROPHONES

The mechanical problem of the accurate assembly of ceramic discs to form a stack should be appreciated at the very outset of any new design of hydrophone or transducer in which this arrangement of active material is used, and every attempt should be made to include some jig assembly facility as an integral part of the design. A convenient jigging method is a central bolt calling for a hole in the ceramic discs and electrodes. In the case of a hydrophone this central hole need not exceed 5/16 inch diameter as it is not intended nor needed for a pre-stressing rod. The nearest standard sized disc acceptable in the design should always be used, as this will keep the cost down and the delivery time to a minimum. It will, of course, be necessary to specify the hole size and the tolerance limits on this hole (say + .003"). This requirement unfortunately adds to the cost of the disc due to extra grinding required, however it is felt that this extra cost is more than offset by the easing of assembly problems. The use of the outer diameter for jigging purposes, has two objections; first, the tolerances as quoted in the manufacturers' brochure are usually exaggerated, and have been found to be in the order of .025"-.030" outside the stated limits. Secondly, the diameter of the end plates of a hydrophone or transducer usually exceeds the diameter of the ceramic disc e.g. to include an '0' ring etc., which means that two separate jigging and sticking operations are necessary, or a specially constructed jig is required. This adds to the cost of and time taken for the manufacture of each assembly, especially as each sticking operation requires at least 24 hours curing time. An important feature in the design of the end plate is a location recess for the outside diameter of the end disc, which will be of insulating material if an electrically balanced arrangement is required. This recess can have a wide tolerance on the diameter but should be further recessed to a depth of .002" to ensure that all the glue is not extruded by pressure (see Fig. 1). The manufacturer should make the following measurements and forward the results with the discs:-

(a) Capacity at 1 Kc/s

(b) Power factor Tan δ at 1 Kc/s

(c) Radial mode resonant and anti-resonant frequencies and the total admittance at these frequencies.

(d) Thickness mode resonant and anti-resonant frequencies where possible and the total admittance at these frequencies.

3. THE DESIGN OF GLUED JOINTS WITH ELECTRODES

In the course of developing high power low frequency transducers where, by the nature of the problem, large masses are needed, a serious limitation of the engineering development has been the relatively low tensile strength of the metal (normally nickel powder) loaded joints which were previously used to bond the ceramic discs and also to provide low resistance contact between the silvered faces and the metal electrodes.

An investigation showed that, unless extreme caution was used in the squeezing jig, the tendency was for the nickel particles to squash flat and extrude most of the bonding glue - giving good electrical contact but very low bond strength. In fact instances occurred where complete assemblies were, shattered in transit.

A series of test on glued joints in general has led to the conclusion that joints should be maintained at .002" glue thickness. These tests will be described fully in a later report.

A method was therefore required to maintain this optimum thickness and ensure electrical contact without recourse to metal loaded glues.

4. DIMPLED ELECTRODE TECHNIQUE

The considerations in the above paragraph led to the dimpled electrode technique being evolved. This technique involves punching each steel electrode .005" thick with small dimples .005" high and approximately .020" across the base. Half are pressed in one face and half in the other. These dimpled electrodes are then sandwiched between silvered ceramic discs and the procedure indicated in the assembly details followed. Static tests have been carried out on these joints and a high value of bond strength achieved, in fact bond strengths exceeded the strength of the ceramic material in many cases, particularly where Lead Zirconate was used.

Transverse cuts were made across the line of dimples in an assembly and also between the line of dimples. Figs. 2 and 3 show how the electrode was aligned between the ceramic discs.

It will be observed that the desired glue thickness is maintained (Fig. 2) only in-between the dimples. In the region of the dimples the glue film (Fig. 3) is wedge shaped. This does not appear to have a detectable weakening effect on the joint compared with a uniform film. Satisfactory electrical contact can be achieved where the number of dimples is between 10 and 15 per square inch.

The procedure to ensure contact is to compress the joint by .005", until the electrode is sprung into the shape shown in Fig. 3, and then another .001" making .006" in all. This leaves .004" total glue thickness which divides itself into .002" on each side of the electrode over the major area of the joint (Fig. 2).

5. ASSEMBLY INSTRUCTIONS

(a) All the piezo ceramic discs should be carefully checked in order to determine whether the polarity indicated by the manufacturer is the correct one; this can be done very simply by using a valve voltmeter and applying pressure to the discs, care must be taken to apply the pressure in such a way as to avoid any bending moment on the disc which can lead to spurious results. The polarity found should be lightly scratched on the silvered faces of each disc as any form of paint or ink etc. is removed during the cleaning operation.

(b) The capacity and power factor (tanα) of each disc should be measured at 1 Kc/s and the value noted for each disc of the assembly.

(c) All components should be high-frequency cleaned for not less than 20 minutes, care being taken to use a fresh cleaning agent each time; in this case the suggested agent is Trichlor-Ethylene No. 7.

Do not exceed the stated time for cleaning as the temperature of the cleaning agent may rise rapidly due to the power dissipation in some cleaning baths and if the ceramic being used is Barium Titanate there is a serious risk of de-polarization (80°C).

(d) Having cleaned all parts, place them under a belljar or dust cover and mix the glue; a convenient quantity for a small number of stacks is 20 grams of resin and 3.0 grams of hardener. Thoroughly mix the hardener with the resin, avoiding too vigorous beating which will entrap air, and allow to stand in a covered wide shallow dish for half an hour. This allows captive air bubbles to escape from the mixture; evacuation of the mix can be carried out at this stage but should not be necessary if the mixing has been carefully performed.

<u>CAUTION</u>: Care should be taken to mix the glue in a fume cupboard as the fumes have an injurious effect on the eyes; also do not allow the glue or the hardener to come into contact with the skin at any time during the operation.

(e) Using a clean set of tweezers or tongs to hold the components, apply the glue, assemble the stack in the order required, making sure that correct polarities are maintained.

(f) Having assembled the stack in the required order, wire up the electrodes temporarily (usually in parallel) and connect the output leads to a capacity bridge. Screw down the assembly lightly until a capacity reading equal to the sum of the combined capacities of the discs forming the stack is recorded.

(g) Measure the length of the stack at this stage or mount a clock indicator on the top face, and continue to screw down until the stack has been compressed an amount equal to .006" per joint. Wipe off the excess glue which has extruded from the joints and place the assembly in the oven and cure for 24 hours at 40°C.

(h) Remove the assembly from the oven and wire up the electrodes. Then measure the capacity again to ensure that the dimples are in contact. Generally a 10 per cent drop in capacity is observed at this stage due to the heat cycle experienced by the ceramic; this effect has been found experimentally and the reasons for it will be dealt with in a later note.

(i) Place the whole assembly in the high frequency cleaner if this is possible and clean off the solder flux using Ethyl Methyl Ketone as the cleaning agent.

(j) At this stage it has been found worthwhile to coat the outside of the stack with a water or moisture-impervious epoxy resin.

The Minnesota Mining and Manufacturing Co's Scotch Cast Resin No. 4 has been found to keep the insulation of the stack permanently at a high level.

<u>NOTE</u>: Epophen 841 is very hygroscopic and the insulation qualities rapidly deteriorate in contact with moisture.

(k) The theoretical longitudinal resonance should be calculated and the assembly connected to a swept frequency meter e.g. Bruel and Kjaer Lever Recorder. The response at the longitudinal resonant frequency should give a clean trace and maximum amplitude. If the curve shows a number of small resonances near the expected main resonance and the amplitude is low, or if the main resonance is much different in frequency than calculated, this is a clear indication of bad joints, and serious thought should be given to the rejection of the stack.

It is worth noting that lead zirconate ceramic discs can be recovered by heating a stack assembly to 130-150°C at which temperature the joints can be parted quite readily with a razor blade. The discs can then be cleaned and re-used without any detrimental effect on the ceramic.

6. HEALTH HAZARDS

The precautions in 5 (c) above cannot be too greatly emphasised. These glues and particularly their hardeners can cause severe dermatitis and conjuntivitis, even from fumes, in a sensitive person. It is unfortunate that 'safe' hardeners which have been developed invariably produce a much lower joint strength.

No one should regard himself as immune as continued contact will eventually develop an allergiv sensitivity which, once, developed, apparently does not disappear again.

7. CONCLUSIONS

The instructions in section 5 if accurately adhered to will produce reliable stack assemblies comparable with the best of any alternative systems. They may therefore be usefully used as a guide to training persons or manufacturers new to the techniques.

8. ACKNOWLEDGEMENTS

The author would like to thank J. ELLIOT for his design and manufacture of the jigs associated with the tests carried out on this work.

C.M. Hubbard (S.A.(Sci.))
ARL/EH

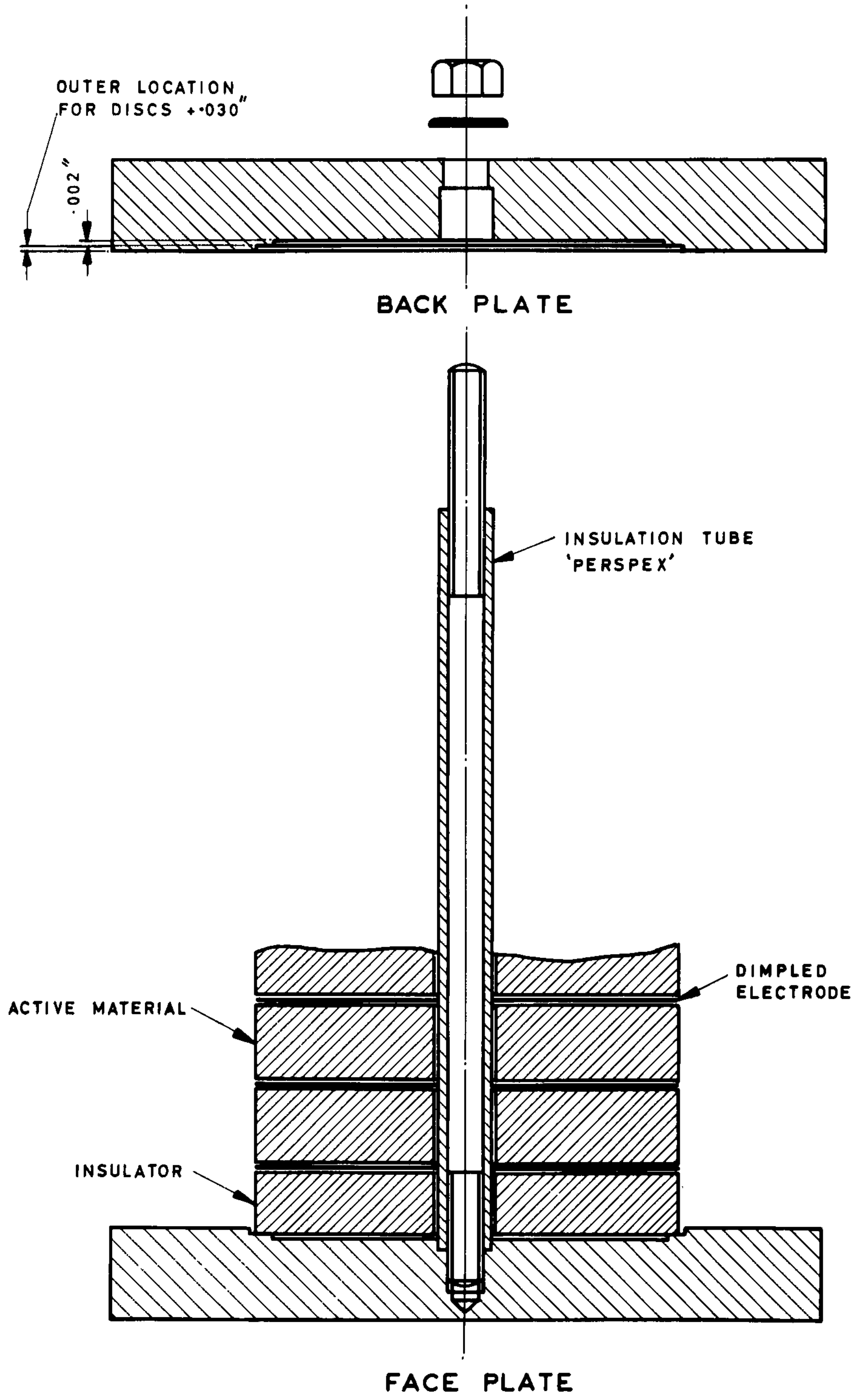
OUTER LOCATION
FOR DISCS +·030"
·002"
BACK PLATE
INSULATION TUBE
'PERSPEX'
DIMPLED
ELECTRODE
ACTIVE MATERIAL
INSULATOR
FACE PLATE

FIG 1

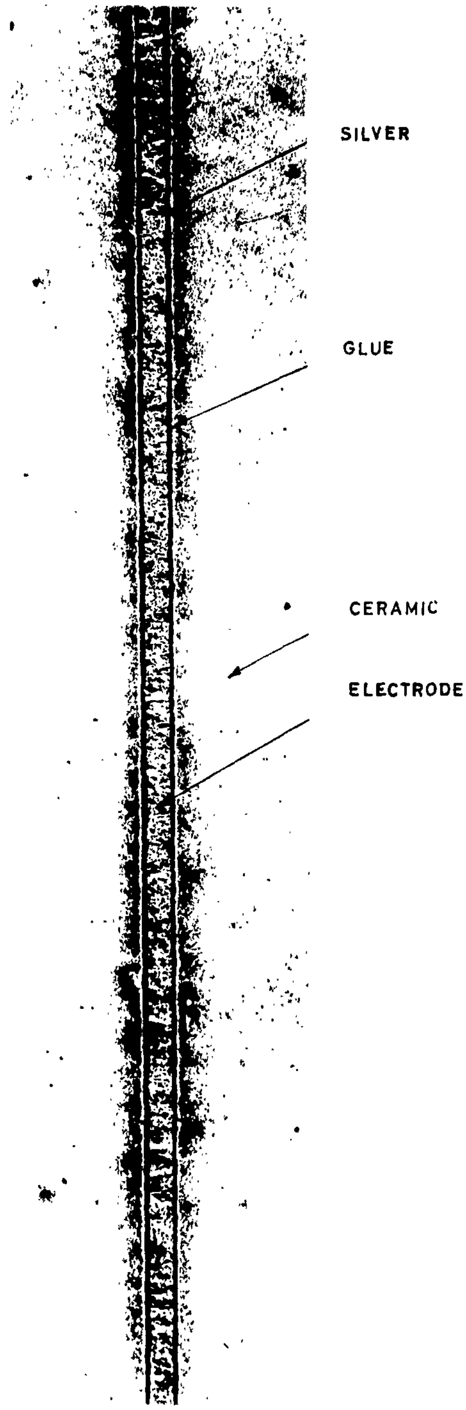

FIG. 2
BETWEEN DIMPLES

FIG. 3
ACROSS DIMPLES

SECTION THROUGH DIMPLE ELECTRODE

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