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**RECOMMENDED PROCEDURE FOR EVALUATING
PERMANENCY OF RESIDUAL POLARIZATION
IN FERROELECTRIC CERAMICS**

by
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August 1959

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RECOMMENDED PROCEDURE FOR EVALUATING PERMANENCY OF RESIDUAL POLARIZATION IN FERROELECTRIC CERAMICS

Different techniques and procedures are practiced for polarizing ferroelectric ceramics. All are intended to create the maximum degree of residual polarization, or bound charge, in a particular composition. One must quite definitely evaluate the degree of effective residual polarization established before attempting to determine the permanency of this phenomenon. There are several ways of establishing the degree of residual polarization that might be discussed. However, the procedures proposed here will be confined to what is thought to be the most practical ones which apply directly to the applications for which the materials are intended. For instance, if elements are being produced for some high frequency drive, such as delay line applications, one should establish the effective degree of polarization by measuring electromechanical coupling on the actual specimens.

If the elements are to be used where they will be mechanically stressed to produce charge and the resultant voltage output, then one should measure piezoelectric coefficient by stressing the specimens and measuring charge produced. This is in agreement with the opinions expressed at our brief conference at Rutgers University, that all properties on piezoelectric specimens should be evaluated in a manner which will give data applying directly to the application for which they are intended.

After electromechanical coupling or piezoelectric coefficients have been established to indicate the effective degree of residual polarization on a number of specimens, it might be advisable to correlate the degree of efficiency indicated by these measurements with the degree of residual polarization indicated possible by hysteresis loop observation. If good correlation can be obtained in this manner, fabricators of such elements might employ the hysteresis loop method for evaluating elements for definite application before electroding or polarizing, if the specimens were lightly clamped between soft conducting rubber electrodes. In this way the poor specimens could be sorted out before electroding or polarizing.

In the proposals made for determining retentivity of polarization, this direct application view will be maintained; therefore, several recommendations for evaluation will be made, each recommended for elements for different applications.

1. For elements to be driven at high frequencies and intensities under steady state or pulse conditions and working into high mechanical impedances, such as those used for delay line application, the following test procedure would be recommended:

Elements of normal geometric dimensions should be used. These should be polarized in the prescribed manner and the electromechanical coupling coefficient accurately established by the resonance-anteresonance method. Then they should be driven for long periods at the approximate frequency of interest, both continuous and pulsed. This should be done over a temperature range somewhat wider than expected in the proposed application and at somewhat greater intensities. At definite intervals, resonant and anteresonant frequencies should be again measured to observe any drop in electromechanical coupling which would indicate loss of residual polarization. If little or no drop in coupling is observed after a reasonable period of drive, the element should be clamped firmly between flat plates of high mechanical impedance material (fused quartz) and driven to determine the effect of combined electrical and mechanical stress on the polarization. Experience would determine a desirable cycle for such evaluations of retentivity of polarization.

2. For elements to be mechanically stressed, at high rates over some appreciable range, to develop voltages on a high impedance termination such as duplex elements for phonograph pickup units, and so forth.

Some standard stressing equipment such as a calibrated dynamic drive (moving coil) should first be set up for mechanically driving such elements, where the amplitude of motion providing the stress would be adjustable over the range of interest. This equipment should be capable of stressing such elements somewhat beyond that which they would receive in normal practice, and should be designed to do this at any and all frequencies of interest and do it over an expanded temperature range. In such applications where the stress could, depending on the geometry and lever system employed, be quite high in certain areas of the specimen, one must recommend that this mechanical abuse be applied while the specimen is working into normal impedance loads. These impedance loads have a direct bearing on the voltage stress across the element which can, under certain conditions, be very detrimental to the polarization.

Experience should indicate the desired cycle for such evaluations on retentivity of polarization.

3. For elements working into both high and low impedance loads and subjected to nondestructive high impact and quasi-static stresses, where these stresses may be applied at rates from a few microseconds to a few seconds and go as high as 50,000 to 60,000 psi, quite different procedures must be recommended.

First the effective degree of residual polarization must be established. It is recommended this be done by measuring piezoelectric coefficient (d_{33} -charge produced when stressed parallel to the polarized axis) on actual specimens. This piezoelectric coefficient should be measured under conditions closely approximating those of the planned application. Because of variations that have been demonstrated in charges produced and voltages developed under the higher stress conditions when working into different terminations, the retentivity of polarization in specimens for such use must be evaluated while working into load impedances representative of the actual application conditions. It would be necessary to apply stresses up to somewhat greater magnitudes, at rates comparable to and greater than those expected in practice; then, measure the charge produced and resultant voltage generated as demanded for the application. The charge produced will permit determination of

the piezoelectric coefficient characteristic as the magnitude of stress is increased. This should be done for all termination conditions of interest. The stress range should be increased in definite steps for each condition, until maximum expected stress is somewhat exceeded. All this should be done over an expanded temperature range and the deterioration in output, if any, observed. One should, after some experimental data are compiled, be able to stipulate how many stress impulses of certain magnitude and rise rate should be applied to specific specimens, working under prescribed circuit and temperature conditions, without showing more than a given percent deterioration. This deterioration or loss of effective residual polarization will surely be a function of the following factors:

- a. Load impedance,
- b. The total mechanical stress applied,
- c. The positive voltage gradient developed across the specimen,
- d. The negative voltage gradient produced across the specimen.

This negative voltage gradient (opposite to the original polarization field) can be very high, if the charge due to a high positive stress is allowed to flow off before this stress is removed. This negative voltage gradient has been shown to be very detrimental to the residual polarization.

A specific amount of such data should permit one to specify the number of stressing cycles of given degree a particular specimen should be required to stand, under well-defined conditions without losing more than a given percent of its effective residual polarization.

It has not been stated that either electromechanical coupling or piezoelectric coefficient is directly proportional to the degree of residual polarization, nor is it thought to be. However, the slope of some graph indicating efficiencies of such elements, driven electrically or stressed mechanically, will certainly vary with the degree of residual polarization. Consequently, since we are primarily interested in efficiencies of such elements, it is strongly recommended the effective degree of residual polarization in such specimens be evaluated by checking the actual output from them in a normal circuit.