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NRL Memorandum Report 5687

**Ad Hoc Subcommittee Report on Piezoceramics -
Revision of DOD-STD-1376A (SH)**

Edited by

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1 April 1986

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**NAVAL RESEARCH LABORATORY
Washington, D.C.**

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An ad hoc subcommittee on piezoceramics, under the sponsorship of the American Defense Preparedness Association (ADPA), has revised DOD-STD-1376A(SH). The revision represents the collective thoughts of Government agencies, laboratories, industrial manufacturers, and universities who critiqued the existing standard and suggested areas for clarification and improvement. Major changes to the standard include the addition of two more materials, essentially non-overlapping ceramic parameters, expanded user guidelines, and hydrophone and projector specifications combined for simplicity.			
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**AD HOC SUBCOMMITTEE REPORT ON PIEZOCERAMICS -
REVISION OF DOD-STD-1376A(SH)**

STATEMENT OF SPONSORSHIP AND CHARTER

The ad hoc subcommittee for piezoceramic was formed as a subsection under the sponsorship of the American Defense Preparedness Associations (ADAP) Sensor Section within the Undersea Warfare Division. Its purposes included:

- A forum to advance the technology of piezo materials through improved quality, reliability, repeatability, and uniformity.
- Foster better, closer working relationships between piezo manufacturers and piezo users.
- Provide a study output that would ultimately manifest itself as improvements in transducer technology.

The major objective was to review and update MIL-STD-1376(SHIPS), Piezoelectric Ceramics for Sonar Transducers, 21 Dec 1970, and, subsequently, DOD-STD-1376A(SH), 28 Feb 1984.

Funds for the publication of this report were provided by Mr. R. E. Heaney, Naval Sea Systems Command, SEA63X5B, through the Sonar Transducer Reliability Improvement Program (STRIP), Dr. R. W. Timme, Program Manager, Naval Research Laboratory, Underwater Sound Reference Detachment.

MEMBERS OF THE AD HOC SUBCOMMITTEE ON PIEZOCERAMIC

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Roy E. Heaney (Vice Chairman)	- Naval Sea Systems Command
Cas Stevens (Secretary)	- Vernitron Piezoelectric Division
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Mark Rickman	- Piezo Electric Products, Inc.

SOLICITATION OF GOVERNMENT, INDUSTRY, AND UNIVERSITIES

A letter, drafted by the subcommittee, was sent from the Chairman with a cover letter from NAVSEA 63X5B inviting activities involved in the development and/or manufacturing of piezoelectric materials for the military, and in the design of military transducers, to aid the subcommittee in the development of a viable revision to MIL-STD-1376(SHIPS).

Over 30 activities plus the committee members and their respective affiliations were solicited to critique, to provide suggestions, and to present their views and recent experience regarding the use or misuse, and/or any changes to the current version of the standard. Those solicited included:

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FINAL REPORT BY THE CHAIRMAN

TO: C. McQueary
Chairman, Sensor Section of Undersea Warfare Division of ADAP

SUBJ: FINAL REPORT OF THE PIEZO AD HOC SUBCOMMITTEE

The Piezoelectric Ad Hoc Subcommittee (PAS) has completed its study and proposed revision of DOD-STD 1376A(SH), Piezoelectric Ceramic for Sonar Transducers. This revision represents the collective thoughts of Government agencies and laboratories and industrial piezo manufacturers, and addresses the comments submitted by a broad spectrum of Navy transducer manufacturers who were asked to critique the existing standard and suggest areas for clarification and improvement. The following text is a greatly improved, embellished, and more easily usable document that is considerably more definitive and should allow the users of the document, both Navy and contractors, to more accurately specify material.

The improvements are diverse and address the following areas:

1. The revision is established as a guideline document and should be used with a procurement specification.
2. Two compositions of ceramic material have been added.
3. Table of parameters have been adjusted to be self-consistent and essentially non-overlapping.
4. The specification is written to be more specific and says what is implied, in addition to expanding user guidelines.
5. The specification has been improved, clarified, simplified, and reformatted, and it is far less ambiguous.

6. Hydrophone and projector specifications have been combined for simplicity.
7. Cautions and caveats have been included as appropriate.
8. Expanded appendices include formulae to transpose parameters from one mode to another.
9. Curves have been replotted for easier use.
10. The electrode adhesion test has been revised.
11. The document is user friendly.

The revised standard is being submitted to the Navy via the Transducer Division (SEA63X5) with the intention of publication by the Standards Committee.

The Program Manager (NRL-USRD Code 5977) for the Sonar Transducer Reliability Improvement Program (STRIP) and his sponsor (NAVSEA 63X5) have approved the specification as an interim document for distribution to Navy agencies and support contractors until the actual revised DOD-STD is published in order that an immediate reference can be established for formal use during the interim period.

The Subcommittee has also looked toward future improvements in piezo technology and has partially listed below the areas that need continuing Navy sponsorship and Government/industry investigation.

1. Measurement and Test Techniques

- Measurement technique for d_{33} optimization
- Measurements of other shapes (other than discs and rings)
- Strength of materials and test methods (for shock hardening)
- Measurement of piezo properties under multiple constraints (voltage, temperature, pressure, etc)
- Corona measurements

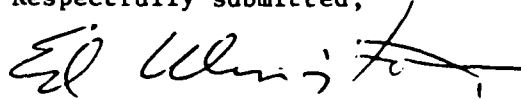
2. Investigation and Analysis

- Mechanical stress dependency (i.e., influence of static stress)
- Temperature - Influence of heat stabilization after polarization
- Additional compositions
- Optimization of adhesion (e.g., tape tests, etc)

A.C. TIMS

The Subcommittee appreciates the cooperation and interest of all those who helped in the preparation of the document with a special thanks to Lu'Anne Jevnager of the Technical Information Office at NRL-USRD. We appreciate the opportunity to be of service in the national interest.

Respectfully submitted,

A handwritten signature in dark ink, appearing to read 'Ed Winston', with a stylized flourish at the end.

ED WINSTON
Chairman
Piezo Ad Hoc Subcommittee

DOD-STD 1376(XX)
SUPERSEDES
MIL-STD-1376(SHIPS)
21 DECEMBER 1970
AND
DOD-STD-1376(SH)
28 FEBRUARY 1984

MILITARY STANDARD

**PIEZOELECTRIC CERAMIC MATERIAL AND MEASUREMENTS
GUIDELINES FOR SONAR TRANSDUCERS**

PROPOSED
STANDARD

A.C. TIMS

DEPARTMENT OF DEFENSE
WASHINGTON, D.C. 13062

PIEZOELECTRIC CERAMIC FOR SONAR TRANSDUCERS

MIL-STD-1376X(XX)

1. This Military Standard is approved for use by the Naval Sea Systems Command, Department of the Navy, and is available for use by all Departments and Agencies of the Department of Defense.
2. Beneficial comments (recommendations, additions, deletions, and any pertinent data which could be of use in improving this document) should be addressed to: Commander, Naval Sea Systems Command, SEA55Z3, Department of the Navy, Washington, DC 20362, by using the self-addressed Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

FOREWORD

1. This standard only provides guidelines for designating piezoelectric ceramic material properties and measurements for use in sonar transducers. Deviations from the properties of the standard ceramic types are acceptable when required by the individual equipment specification provided the properties so modified are self-consistent. This document is not intended to replace a procurement specification and/or drawing for individual ceramic elements. All essential requirements for physical, mechanical, and piezoelectric properties must be completely stated, with appropriate tolerances and test requirements, in the individual ceramic element procurement specification.

2. The general properties specified permit a wide range of values for each type ceramic and are included in this standard solely for the purpose of defining the types of piezoelectric ceramic intended for use in Navy sonar transducers. Some of the properties and their associated values specified can be determined only by measurement on a specific geometric shape; e.g., a thin disc, and values for these properties, such as the coupling factor and frequency constant, should not be specified in the acquisition of ceramic elements which do not meet the necessary geometric criteria. The individual specification for ceramic elements shall list required measurements and values, some of which can be only determined from actual measurements on the specific ceramic material and shape.

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1. SCOPE

1.1. Scope. This standard describes six types of piezoelectric ceramic materials utilized to manufacture sonar transducers for the Naval service. This standard also describes the properties of the ceramic compositions for these six types as measured on standard test specimens.

1.1.1. Appendices attached provide clarification and assistance in the use of this standard.

1.2. Classification. This standard is unclassified.

2. REFERENCED DOCUMENTS

2.1. Issue of documents.

2.2. Publications. The following publications form a part of this standard to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids or request for proposal shall apply.

NONGOVERNMENTAL

AMERICAN NATIONAL STANDARD INSTITUTE (ANSI)

ANSI Y14.5M-1982 - Dimensioning and Tolerancing, (DoD adopted). (Application for copies should be addressed to the American National Standards Institute, 1430 Broadway, New York, NY 10018).

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

ASTM-E380 - Metric Practice. (DoD adopted). (Application for copies should be addressed to the American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.)

ASTM-E29-67 - Indicating which places of figures are to be considered significant in specifying limiting values.

INSTITUTE OF ELECTRICAL AND ELECTRONIC ENGINEERS (IEEE)

IEEE 176-1978 - Standard on Piezoelectricity. (Application for copies should be addressed to the Institute of Electrical and Electronic Engineers, 345 East 47th Street, New York, NY 10017.)

(Technical society and technical association specifications and standards are generally available for reference from libraries. They are also distributed among technical groups and using Federal agencies.)

3. DEFINITIONS

3.1. **Terminology.** The terminology used in this standard is based on definitions given in IEEE 176-1978 except as follows:

3.1.1. **Standard test specimens.** The standard test specimens intended for verification of the material properties as defined in this standard will be in the form of thin discs as specified in paragraph 5.1.

3.1.2. **Ceramic elements.** Ceramic elements are those piezoelectric ceramic shapes (for example, bars, cylinders, discs, plates, rings, spheres, and hemispheres) capable of satisfying specific transducer requirements and are referred to as first-article and production ceramic elements in this standard.

3.1.3. **Individual equipment specifications.** See Appendix A for general guidelines.

3.2. **Units and symbols.** The International System of Units (SI) as shown in ASTM Standard E 380 has been used where practical. A glossary of the symbols used in this standard is shown in Table I.

3.3. **Dimensioning and tolerancing.** The dimensioning and tolerancing used to define the required condition of a part or component on an engineering drawing shall be in accordance with ANSI Y14.5M.

3.4. **Rounding off of data.** For purposes of determining conformance with these specifications, an observed value or a calculated value shall be rounded off "to the nearest unit" in the last right-hand place of figures used in expressing the limiting value, in accordance with the rounding-off method of ASTM Recommended Practice E29, for indicating which places of figures are to be considered significant in specified limiting values.

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TABLE I - Glossary, Symbols, Definitions, and Units.

SYMBOL	DEFINITION	UNIT
C^T	Free capacitance (low frequency)	farad (F)
D	Diameter	meter (m)
d_{31}	Piezoelectric constant, strain/field at constant stress	meter/volt (m/V)
d_{33}	Piezoelectric constant, strain/field at constant stress	meters/volt (m/V)
ϵ_0	Permittivity of free space	8.8542×10^{-12} F/m
ϵ_{33}^T	Free permittivity of material (low frequency)	farads/meter (F/m)
E	Applied electric field	volt/meter (V/m)
f_m	Frequency of maximum admittance (minimum impedance)	hertz (Hz)
f_n	Frequency of minimum admittance (maximum impedance)	hertz (Hz)
g_{31}	Piezoelectric constant, field/stress at constant charge density	volt meters/newton (Vm/N)
g_{33}	Piezoelectric constant, field/stress at constant charge density	volt meters/newton (Vm/N)
k_{33}^T	Free relative dielectric constant = $\epsilon_{33}^T / \epsilon_0$	
k_{eff}	Effective coupling factor, $k_{eff} = \left[(f_n^2 - f_m^2) / f_n^2 \right]^{1/2}$	
k_p	Planar coupling factor (see figure 1)	
l	Length	meters
N_p	Frequency constant planar mode disc, $N_p = (f_m D)$	hertz meter (Hz m)
Q_m	Mechanical quality factor, $Q_m = Y_m / 2\pi f_m C^T k_{eff}^2 $	
ρ	Density	kilogram/meter ³ (kg/m ³)
σ^E	Poisson's ratio, $\sigma^E = -s_{12}^E / s_{11}^E$	
s_{ij}^E	Elastic compliance coefficient at constant electric field	meter ² /newton (m ² /N)
s_{ij}^D	Elastic compliance coefficient at constant electric displacement	meter ² /newton (m ² /N)
t	Thickness	meter (m)
tan δ	Dielectric loss factor	
w	Width	meter (m)
Y_m	Maximum admittance magnitude	siemens(s) (previously mhos)
Y_n	Minimum admittance magnitude	(siemens(s) (previously mhos)

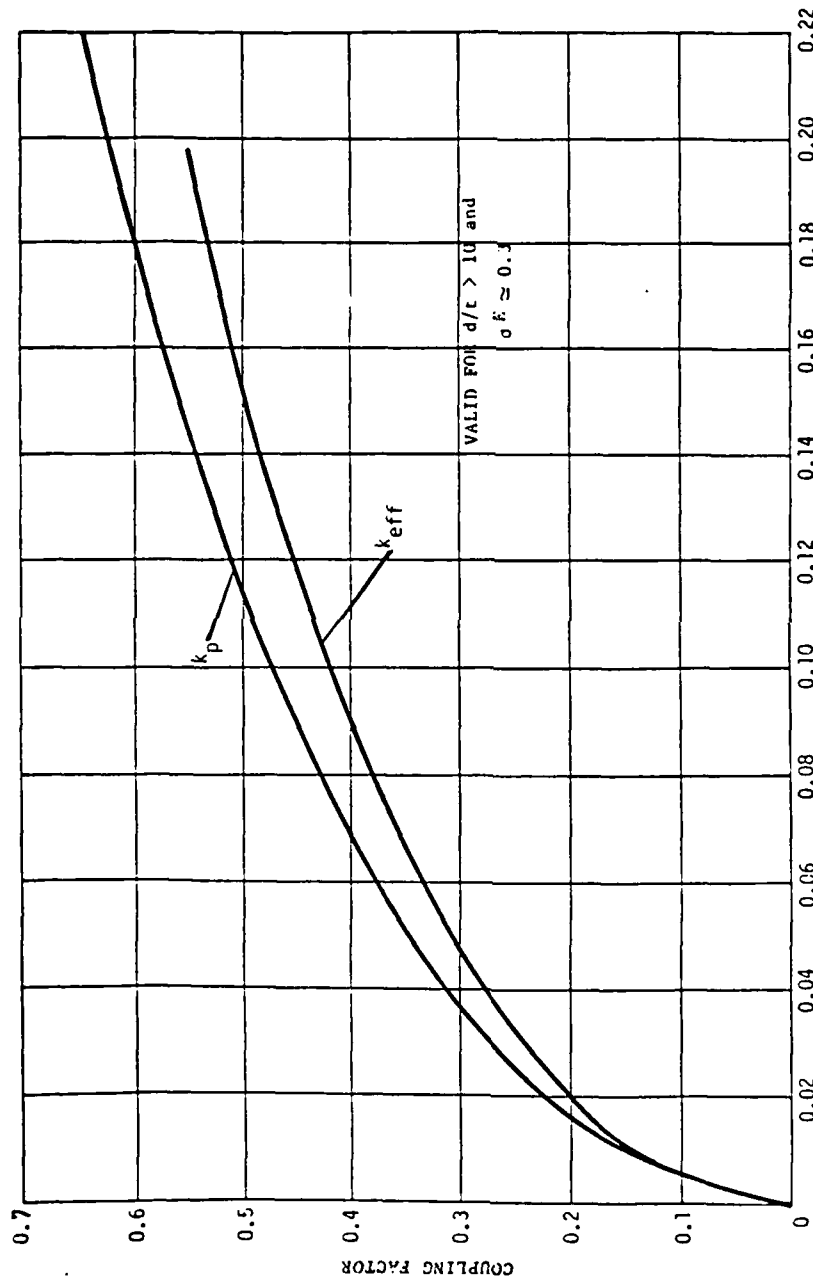


FIGURE 1. Planar and effective coupling factor as a function of $\Delta f/f_m$.
 NOTE: Although $k_{eff}^2 = (f_n^2 - f_m^2)/f_n^2$, k_{eff} is plotted as a function of $\Delta f/f_m$ for convenience.

4. GENERAL REQUIREMENTS

4.1. Standard ceramic types. The standard ceramic types are defined below. It is difficult to avoid the use of relative terms to describe the materials listed. Thus, for an absolute or more complete comparison, tables (with quantitative data) of pertinent properties should be consulted.

- TYPE I A modified lead-zirconate-titanate composition generally recommended for medium- to high-power acoustic applications. Its "resistance" to depoling at high electric drive and/or mechanical stress makes it suitable for deep-submersion acoustic applications.

- TYPE II A lead zirconate-titanate composition modified to yield higher charge sensitivity but one that is not suitable for high electric drive due to dielectric heating. This material is more suitable for passive devices such as hydrophones. Advantages also include better time stability.

- TYPE III Similar to Type I but greatly improved for use at high electric drive because of lower losses. Its field dependency of dielectric and mechanical losses is substantially reduced. However, at low to moderate electric-drive levels Type I material may actually be a better choice because of greater electromechanical activity.

- TYPE IV A modified barium-titanate body for use in moderate electric-drive applications. It is characterized by lower piezoelectric activity and lower Curie temperature than any of the lead zirconate-titanate compositions.

- TYPE V A composition intermediate to Types II and VI and thus to be used accordingly.

- TYPE VI Similar to Type II with higher charge sensitivity and dielectric constant, at the expense of a reduced Curie temperature.

4.1.1. Standard ceramic type compositions. The standard ceramic types to be used in sonar transducers shall have properties as shown in Tables II and III. The properties shall be measured on standard test specimens as defined in Sections 5 and 6. Lead-zirconate-titanate compositions having an approximate zirconium/titanium (Z_r/T_i) ratio of 53/47 are typically modified with additives to meet the requirements of Tables II and III, except as specified in paragraph 4.1.1.1.

Table II - General Properties and Small Signal Values of Ceramic Standard →

MATERIAL TYPES		I		II		III	
PROPERTY	SYMB	TYPICAL VALUES	AGING RATE ^{1/}	TYPICAL VALUES	AGING RATE ^{1/}	TYPICAL VALUES	AGING RATE ^{1/}
Free Rel. Diel. Const.	K_{33}^T	$1275 \pm 12.5\%$	-4.5 ± 2.0	$1725 \pm 12.5\%$	-1.5 ± 0.7	$1025 \pm 12.5\%$	-4.0 ± 1.5
Diel. Loss Factor	$\tan \delta$	≤ 0.006		≤ 0.020		≤ 0.004	
Planar Coupl. Factor ^{2/}	k_p	$0.58 \pm 8.0\%$	-2.0 ± 1.0	$0.60 \pm 8.0\%$	-0.25 ± 0.15	$0.50 \pm 8.0\%$	-2.0 ± 1.0
Piezoelectric Coefficient ^{3/} 10^{-12} m/V	d_{33}	$290 \pm 15\%$		$390 \pm 15\%$		$215 \pm 15\%$	
Planar Freq. Constant Hz-m ^{4/}	N_p	$2200 \pm 8.0\%$	1.3 ± 0.8	$1950 \pm 8.0\%$	0.20 ± 0.10	$2300 \pm 8.0\%$	1.3 ± 0.8
Density 10^3 kg/m ³	ρ	≥ 7.45		≥ 7.60		≥ 7.45	
Mech. Qual. Factor ^{5,6/}	Q_m	> 500		> 75		> 800	
Percentage Change in K_{33}^T 0° to 50°C ^{6/}		9.5 ± 3.0		25 ± 10		9.0 ± 3.0	
Approx. Curie Temp. °C		325		350		325	

1/ The aging rate is the typical change in properties up to 100 days after poling using the 10-day value as the base expressed in percent per time decade.

2/ The planar coupling factor, k_p , will be determined from Fig. 5, where f_n is the frequency of minimum admittance and f_m is the frequency of maximum admittance; f_m to be measured at fields < 100 V/m.

3/ d_{33} is a new value added to the Table. The values shown are calculated values based on Appendix C. A method of measurement of d_{33} has not been standardized as of the revision date of this document.

Types Measured with the Standard Disc (10-Day Values).

IV		V		VI	
TYPICAL VALUES	AGING RATE ^{1/}	TYPICAL VALUES	AGING RATE ^{1/}	TYPICAL VALUES	AGING RATE ^{1/}
1275 ± 12.5%	-1.50 ± 0.50	2500 ± 12.5%	-2.0 ± 1.0	3250 ± 12.5%	-2.0 ± 1.0
≤ 0.010		≤ 0.025		≤ 0.025	
0.30 ± 8.0%	-1.50 ± 0.50	0.63 ± 8.0%	-0.25 ± 0.2	0.64 ± 8.0%	-0.25 ± 0.2
140 ± 15%		495 ± 15%		575 ± 15%	
3150 ± 8.0%	0.40 ± 0.20	1950 ± 8.0%	0.35 ± 0.2	1940 ± 8.0%	0.35 ± 0.2
> 5.50		> 7.40		> 7.40	
> 400		> 70		> 65	
5.0 ± 2.0		30 ± 10		40 ± 10	
115		240		180	

^{4/} Planar mode disc $N_p = (f_m D)$.

^{5/} The mechanical quality factor, Q_m , defined by $Q_m = Y_m / (2\pi f_m C^T k_{eff}^2)$ where C^T is the small signal capacitance measured at 1 kHz, Y_m is the maximum admittance measured at f_m .

^{6/} Values for the mechanical quality factor and the change in k_{33}^T with temperature are not 10-day values but shall be measured at approximately 100 days.

Table III- Large Signal Dielectric Properties of Ceramic Standard Types (Measured in Air)
at One Discrete Frequency from 60 to 1000 Hz Measured with a Standard Disc.

MATERIAL TYPES		I		III		IV	
		FIELD E IN kV/m					
SYMBOL		200	400	400	150	300	
Change from Low Field Value in %	ΔK_{33}^T	≤ 7.0	≤ 20.0	≤ 4.5	≤ 7.0	≤ 14.0	
	$\tan \delta$	≤ 0.020	≤ 0.040	≤ 0.010	≤ 0.017	≤ 0.035	

4.1.1.1. Modified compositions. Deviations from the properties shown in Tables II and III for the standard ceramic types specified in paragraphs 4.1 and 4.1.1 will be acceptable when required by the individual equipment specification, provided the specified properties so modified are self-consistent.

5. STANDARD TEST DISC CONFIGURATION

5.1. Standard test specimens. Conformance with paragraphs 4.1 through 4.1.1.1 shall be determined by measurements on standard test specimens manufactured in accordance with paragraphs 5.1 through 5.6. The detailed requirements for these specimens are specified in Section 6. Not less than 10 test specimens shall be manufactured for each ceramic type being tested.

5.2 Dimensions and finish of standard test specimen. The standard test specimens for verification of the compositions shall be ceramic discs with a surface finish before electroding not to exceed 1.60 micrometer (63 micro-inch). The 2 flat surfaces of each disc shall be parallel and flat within ± 2 percent of the thickness of the disc. The minimum thickness shall be 2.5 millimeters (0.1 inch). The disc shall be 24.0 millimeters (0.95 inch) minimum diameter and shall have a minimum diameter-to-thickness ratio of 6 to 1. The disc shall be round (diametral tolerance) within 2 percent of the diameter. The dimensional measurements are to be made before electroding.

5.3. Electrodes. Fired silver or electroless nickel electrodes shall be applied to the flat surfaces of the disc.

5.4. Markings. The electrode to which the positive side of the power supply is attached during poling shall be marked as the positive with a suitable designation, such as a dot or +. The disc shall be marked to identify the manufacturer, the powder lot number, and the poling date. The markings shall be as small as practicable, but legible.

5.5. Poling. The standard test disc shall be poled through the thickness.

5.6. Workmanship. The standard test specimens shall meet all requirements specified herein.

6. EXAMINATION AND TESTS FOR STANDARD TEST DISC SPECIMENS

6.1. Method. The measurements of paragraphs 6.2 through 6.10 shall be performed in accordance with the methods of IEEE 176-1978.

6.2. Density. The density, ρ , of each test specimen shall be determined by the Archimedes Method. The measured value shall be equal to or greater than the value shown in Table II for the particular type of material required. The density shall be determined to an accuracy of 0.2 percent.

6.3. Electrical measurements. The electrical measurements shall be made at a temperature between 20°C and 25°C and a relative humidity of less than 60 percent. Each test specimen shall be stored in an environment meeting these conditions for at least 24 hours prior to the measurements. The temperature at which the measurements are made shall be recorded.

6.4. Small signal properties. The 10-day value of the free relative dielectric constant, K_{33}^T , of the dielectric loss factor, $\tan \delta$, the planar coupling factor, k_p , the planar mode frequency constant, N_p , and the piezoelectric constant, d_{33} , of each test specimen shall be established on the basis of a measurement taken preferably at 10 days or during the period of 7 to 14 days after poling and extrapolated to the 10-day values by the use of aging rates determined as specified in paragraph 6.5. The K_{33}^T and $\tan \delta$ shall be measured at 1 kilohertz and nominally 0.25 volts but not to exceed 100 volts per meter.

6.5. Aging rate determination. Measurements for determining aging rates shall be taken at least 3 times. The first set of measurements shall be made within the period 7 to 14 days after poling, the second set approximately 30 days after poling, and the third set approximately 100 days after poling. The data gathered shall be plotted against the logarithm of time in days from poling date and the aging rates (excluding the rate for $\tan \delta$) from 10 to 100 days will be determined by extrapolation using a best fit straight line. Values shall fall within the limits listed in Table II.

6.6. Mechanical quality factor. After the final set of small signal measurements of K_{33}^T , $\tan \delta$, k_p and N_p have been completed, but not later than 110 days after poling, the mechanical quality factor, Q_m , and the temperature characteristics of K_{33}^T shall be measured in that order and the corresponding values shall meet the requirements of Table II.

6.7. Temperature characteristics of K_{33}^T . The percentage change in K_{33}^T shall be determined during a heating cycle. The specimen shall be cooled to 0°C and held at this temperature for 1 hour with the electrodes shorted. Capacitance measurements shall be made at 0°C. The specimen, with electrode shorted, shall be heated to 50°C and stabilized at this temperature for 1 hour and then capacitance measurements shall be made at this temperature. The percentage change shall be determined from these values using the 0°C value as the base, and be in accordance with Table II.

6.8. High-field measurements. After all other measurements are completed, the free relative dielectric constant, K_{33}^T , and the dielectric loss factor, $\tan \delta$, of each test specimen of Type I, or III, or IV shall be measured in air at the electric fields and in the frequency range specified in Table III for the appropriate type of material and the measured values shall be less than or equal to the values shown in Table III. Modified compositions (paragraph 4.1.1.1) used in sonar projector applications shall meet the requirements for the specified type (I, III, or IV) unless otherwise specified in the individual equipment specifications. The K_{33}^T and $\tan \delta$ shall be measured after a dwell of at least 1 minute at each voltage level. The electric field shall be reduced to 0 for 2 minutes between successive measurements.

6.9. Dimensions. The dimensions of each test specimen shall be determined by use of micrometers, calipers, surface flats and gages with certified accuracy to determine conformance with the requirements of paragraph 5.2.

6.10. Electrode resistance. The resistance between any two points (and all points), on each electroded surface shall be less than 1.0 ohm for silver electrodes and less than 3.0 ohms for electroless nickel electrodes.

6.11. Electrode adherence. See Section B4, Appendix B.

6.12. Responsibility for inspection. The contractor is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified, the contractor may use his own facilities or any commercial laboratory acceptable to the Government. The Government reserves the right to perform any of the inspections set forth in the standard where such inspections are deemed necessary to assure that the test specimens conform to prescribed requirements. Test specimens manufactured for a ceramic type in performance of a contract for piezoelectric ceramic elements for the Government or a Government contractor shall be retained for a period of not less than 6 months after delivery of the ceramic elements unless specifically authorized in writing for earlier disposition by the cognizant Government inspector.

6.13. Inspection system requirements. The contractor shall provide and maintain an inspection system acceptable to the Government covering the supplies, fabricating methods, and special tooling. The inspection system shall be in accordance with the data ordering document (see Appendix A) for the standard test specimens.

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APPENDIX A SUGGESTED PROCUREMENT PRACTICES AND DATA REQUIREMENTS

A1. GENERAL

A1.1. Scope When this standard is used in the preparation of a procurement specification or drawing for piezoelectric elements for sonar transducers, it is recommended that the following requirements or some modification thereof be included in the procurement specifications.

A2. DATA

A2.1. Data requirements When this standard is used in an acquisition which incorporates a DD Form 1423, Contract Data Requirements List (CDRL), the data requirements identified below shall be developed as specified by an approved Data Item Description (DD Form 1664) and delivered in accordance with the approved CDRL incorporated into the contract. When the provisions of the Federal Acquisition Regulation (FAR) 7-104.9(n)(2) are invoked, the data specified below shall be delivered by the contractor in accordance with the contract or purchase order requirements. Deliverable data required by this standard are cited in the following paragraphs.

PARAGRAPH NO.	DATA REQUIREMENTS TITLE	APPLICABLE DID NO.	OPTION
3.1.3 and Appendix B, B6.4 and Table BIII	Drawings, engineering and associated lists	DI-E-7031	Level 3 Design activity designation - Contractor drawing numbers - Contractor Delivery of hard copy - Contracting activity.
A2.2	Certificate of compliance	DI-E-2121	-----
A2.5	Inspection system program plan	DI-R-4803	-----

(Data item descriptions related to this standard, and identified in Section 6, will be approved and listed as such in DoD 5000.19L, Vol. II, AMSDL. Copies of data item descriptions required by the contractors in connection with specific acquisition functions should be obtained from the Naval Publications and Forms Center, or as directed by the Contracting Officer.)

A2.1.1. The data requirements of paragraph A2.1 and any task in the standard required to be performed to meet a data requirement may be waived by the contracting/acquisition activity upon certification by the offeror that identical data were submitted by the offeror and accepted by the Government under a previous contract for an identical item acquired to this standard. This does not apply to specific data which may be required for each contract, regardless of whether or not an identical item has been supplied previously (for example, test reports).

A2.2. Certification of manufacturers A prospective piezoelectric ceramic manufacturer shall demonstrate the ability to meet the requirements of this standard for each type of material to be manufactured as follows:

- (a) Manufacture 10 or more standard test specimens of the specific type(s) in accordance with Section 5.
- (b) Perform all tests specified in Section 6.
- (c) Provide the test data to the contracting activity for examination and approval in accordance with the data ordering document.
- (d) When required by the contracting activity, provide the standard test specimens to the designated testing laboratory for further verification.
- (e) Obtain written certification of approval from the contracting activity.

A2.3. Prior certification. A ceramic contractor who has previously manufactured the specific ceramic types shall submit objective evidence of prior test results and certification to the contracting activity. In the event the ceramic contractor has not manufactured the ceramic types during the 2-year period immediately preceding an acquisition, the contractor may be required to be recertified in accordance with paragraph A2.2. The requirements for first-article and production ceramic elements shall be specified in the individual equipment specification.

A2.4. Responsibility for inspection. The contractor is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified, the contractor may use his own facilities or any commercial laboratory acceptable to the Government. The Government reserves the right to perform any of the inspections set forth in the standard where such inspections are deemed necessary to assure that the test specimens conform to prescribed requirements. Test specimens manufactured for a ceramic type in performance of a contract for piezoelectric ceramic elements for the Government or a Government contractor shall be retained for a period of not

less than 6 months after delivery of the ceramic elements unless specifically authorized in writing for earlier disposition by the cognizant Government inspector.

A2.5. Inspection system requirements. The contractor shall provide and maintain an inspection system that is acceptable to the Government and covers the supplies, fabricating methods, and special tooling. The inspection system shall be in accordance with the data ordering document for the standard test specimens.

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APPENDIX B
GUIDANCE IN SELECTION AND SPECIFICATION OF PIEZOELECTRIC CERAMIC

B1. GENERAL

B1.1. Scope This appendix furnishes additional background to be used for guidance and to assist in the selection and specification of a piezoelectric ceramic as required in the individual equipment specification.

B2. REFERENCED DOCUMENTS

B2.1. Issue of documents. Not applicable.

B3. MECHANICAL DEFINITIONS

B3.1. Definitions of physical flaws found in ceramic elements. The individual specifications must specify the maximum size and number of each type of flaw that is acceptable in the ceramic element. Flaws in the ceramic element large enough to degrade the performance for its intended use should be described by the individual specification. Common flaws are listed below.

B3.1.1. Open chips. Flaws at the intersection of two surfaces from which a fragment of the ceramic is missing (see Figure B1).

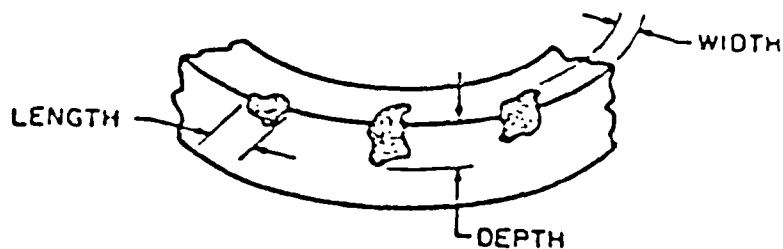


FIGURE B1. Open chips

B3.1.2. Closed chips. Flaws in the ceramic consisting of chips that are not completely removed (see Figure B2).

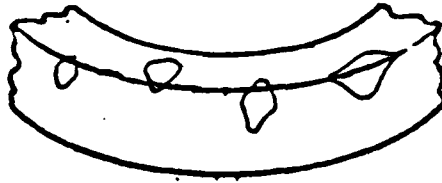


FIGURE B2. Closed chips

B3.1.3. Pits. A pit is an open cavity on any surface (see Figure B3).

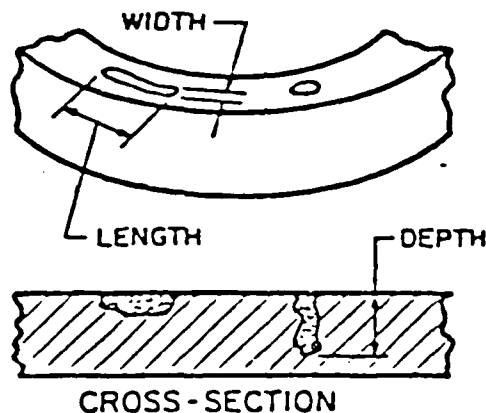


FIGURE B3. Pits

B3.1.4. Cracks. A crack is a break or fissure on the surface or within the ceramic element which mechanically weakens the element and may cause it to part along the line of fracture.

B4. ELECTRODES

B4.1. Electrode materials. Typical electrode materials are fired silver, electroless nickel, copper, electro-plated nickel or gold. Fired silver is the most common type found in the industry. The quality of an electrode is best defined by the three factors: adhesion, surface finish, and conductivity.

B4.2. Electrode adhesion tests. The 2 most common methods of testing for electrode adhesion are: the solder tensile test and pressure-sensitive tape adhesion test which are described in the following paragraphs.

B4.3. Solder tensile test. The solder tensile test method is most widely used for test and acceptance of electrode adherence. Since this method may be a destructive test, the quantity of test specimens per lot or order must be specified.

B4.3.1. Suggested equipment and material.

- (a) Soldering iron - 20 watts (approximately) with small pencil tip (5/64-inch diameter) (preferably a temperature-controlled tip of 550°F).
- (b) Fluxes: noncorrosive rosin flux for fired silver; Superior #30 (or equivalent) for electroless nickel.
- (c) Tinned test wires: #22 AWG tinned solid copper wire or equivalent.
- (d) Solder for silver electrodes: 62 percent tin, 36 percent lead, and 2 percent silver.
- (e) Solder for electroless nickel and other electrodes: 60 percent tin, 40 percent lead.
- (f) A lead alignment fixture.
- (g) Tensile tester: 0 to 111 N (0 to 25 pounds) range.

B4.3.2. Preliminary preparations.

- (a) Allow the soldering iron to preheat for at least 20 minutes before proceeding.
- (b) Thoroughly clean area to be soldered with a mild abrasive device (such as a pencil eraser).
- (c) Flux both the ceramic electrode area to be soldered and the test wire.
- (d) Tin the electrode area and the test wire avoiding excessive flow-out of the solder on the electroded area.

B4.3.3. Soldering procedure.

- (a) Touch tinned tip of lead perpendicular to electrode surface. Obtuse angles will invalidate test.
- (b) Clip lead into alignment fixture with tinned end down.
- (c) Position lead over the clean tinned electrode surface to be evaluated and press down firmly onto the surface to permit flux wetting.

- (d) Immediately touch soldering iron tip to the lead, no closer than approximately 2 to 3 millimeters (0.10 inch) above the tinned end.
- (e) While applying firm downward pressure, heat the lead until solder melts and wets the electrode surface.
- (f) Excessive flowing out of solder on the electrode surface is to be avoided. [Solder dot shall not be greater than 3.0 millimeters (0.12 inch) diameter.]
- (g) It is important to withdraw the soldering iron as soon as the solder melts but not to allow any movement of the lead for at least 5 seconds to allow the solder to solidify into a firm joint.
- (h) After soldered joint has solidified, open the alignment fixture clip and remove the fixture without touching the lead.
- (i) It is not necessary to remove excess flux from the electrode surface.

B4.3.4. Tensile testing.

- (a) Set the tensile tester for the 0 to 111 N (0 to 25 pound) range and set the pointer to 0.
- (b) Install the test sample, exercising care not to cause lateral bending of the lead.
- (c) Exert tensile load on the lead at a rate of 5 to 10 millimeters /minute (0.2 to 0.4 inch/minute).
- (d) Continue loading until the electrode separates or a 35-N (8-pound) pull is indicated on the dial.
- (e) Record the indicated value, relax the load, remove the lead from the fixture, and repeat the test procedures for a total of 6 test leads (3 for each major electroded surface unless otherwise specified). No more than one failure is allowed under 35 N (8 pounds) where failure occurs between the silver and the ceramic. Any failure other than between the silver and ceramic shall be considered invalid and shall be repeated.

NOTE: Exceptions to tensile test: The adhesion test outlined in paragraph B4.3 is not applicable to ceramic parts having a dimension between the electrodes of 1.27 millimeters (0.050 inch) or less. In addition, the tensile test is not applicable where any electroded dimension is smaller than 1.57 millimeters (0.062 inch). Devising a test for inside curved surfaces on cylinders, tubes or other shapes may not always be practicable. In some applications a pressure-sensitive adhesive tape can provide a suitable test (see paragraph B4.4).

B4.4 Pressure-sensitive tape adhesion test. The pressure-sensitive tape method can be used when it is impractical to use solder tensile test or when testing is impossible because of the size or shape of the ceramic element. It should be cautioned that, in addition to the variances on the tape itself, the method of application and testing contains other variables; therefore, materials and procedures should be standardized.

B4.4.1 Standard test specimen procedure. To test the specimen, one electroded surface of all test specimens shall be cleaned with a solvent such as trichloroethane. After the surface is dry, a strip of pressure-sensitive adhesive tape at least 25 millimeters (nominal 1 inch) wide and 70-millimeters (2.76 inches) long with an average adhesion-to-steel value equal to 13.9-N/25 millimeter width (50 ounce/inch), shall be pressed firmly across the diameter of the electrode. The tape shall be in contact with the surface at a temperature between 20°C and 30°C and RH of 60 percent or less. One end of the tape shall then be lifted normal to the electroded surface forming a 90-degree angle. The pull must be even and continuous, without stopping, until the tape is removed. The removal of more than three separate areas larger than 1/16-inch diameter of the electrode surface with the tape shall be considered a failure to pass the test. More than two such failures out of 10 test specimens is unacceptable. (This test applies only to the standard test specimens).

B4.4.2. Ceramic elements procedure. The test procedure and the acceptance requirements shall be specified in the individual equipment or ceramic element specification.

B5. ELECTRICAL DEFINITIONS

B5.1. See Table I.

B5.2. Characteristic frequencies. The characteristic frequencies which are usually required to evaluate the equivalent circuit parameters are the motional (series) resonance frequency, f_s , and the parallel resonance frequency, f_p . There are three pairs of frequencies of interest which coincide for a lossless circuit: that is, $f_m = f_r = f_s$ and $f_n = f_a = f_p$, where f_r is the resonance frequency (susceptance = 0) and f_a is the antiresonance frequency (susceptance = 0); and these occur at the minimum and maximum of impedance, respectively. Since f_s and f_p are difficult to measure directly, f_m and f_n can be used in their place when the losses are small. A vector admittance diagram of a piezoelectric resonator is shown on Figure B4. Additional information can be found in the references.

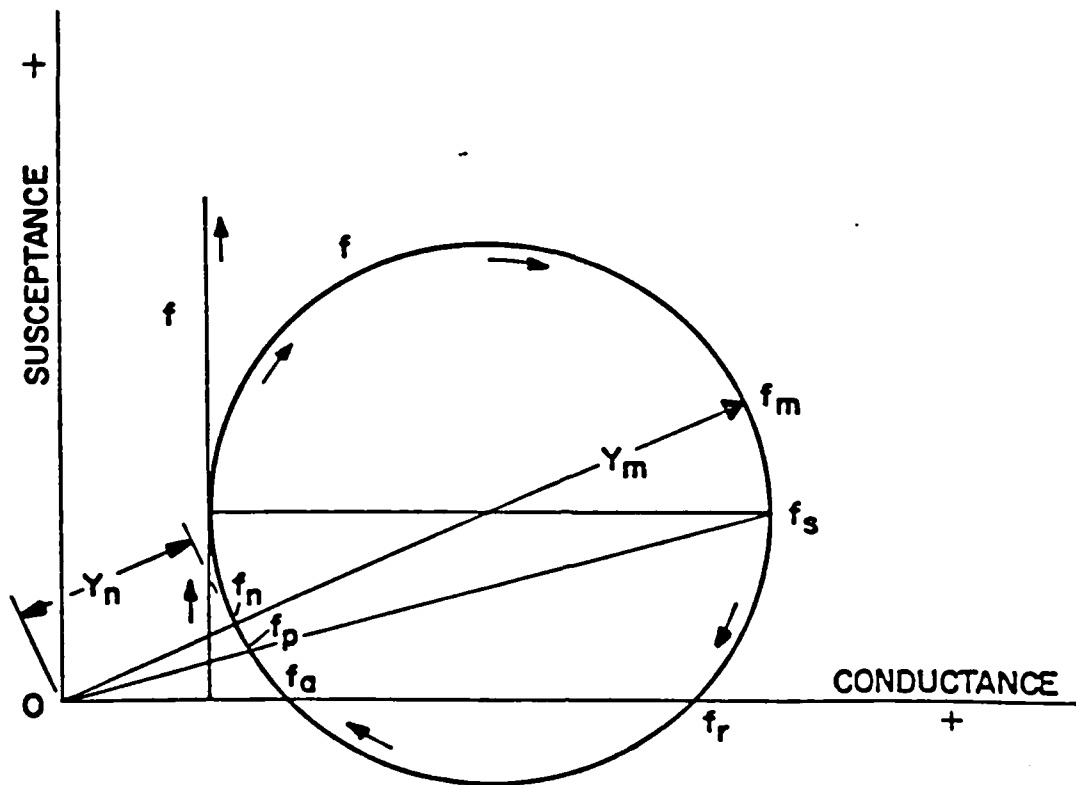


FIGURE B4. Vector admittance diagram of a piezoelectric resonator.

B6. GENERAL REQUIREMENTS

B6.1. Manufacturing variations and restrictions. Because of variations in raw materials, the general properties of piezoelectric ceramic may vary. The ceramic manufacturer is dependent upon suppliers of lead oxide, titanium dioxide, zirconium dioxide, and other constituents with respect to purity, particle size, particle shape, and particle size distribution. All of these parameters introduce variables which may affect the characteristics of the final ceramic. Despite these obstacles to a uniform product, manufacturers of piezoelectric ceramic have developed techniques for adjusting the properties of their product within certain limits that can meet the requirements of most sonar element specifications. Meeting the specifications in production essentially requires the proper combination of dimensional requirements within the elastic, piezoelectric, and dielectric requirements and doing it economically.

B6.1.1. Note that silicone oil shall not be used during poling nor in the processing or manufacturing of ceramics.

B6.2. Guidelines for specifications pertaining to the transducer design.

B6.2.1. This standard is not intended to be used as a production specification for ceramic elements. This standard defines specific Navy piezoelectric ceramic types and provides the broad range of general properties which characterize that type. When specific electro-elastic properties are required, they must be specified in the individual specifications and tolerances established for each parameter. In the event of a conflict within the individual equipment specifications as to material parameter requirements and identification of material type (e.g., I, II, III, etc) the material parameters specified will take precedence.

B6.2.2. It is desirable to specify typical values shown on Table II of this standard. Selection of values other than typical values may be inconsistent with reproducibility, future production, and cost effectiveness.

B6.2.3. When practicable, incorporate within the transducer design a means of accommodating either changes in ceramic dimensions or electroelastic properties.

B6.2.4. Do not restrictively specify both dimensions and piezoelectric properties within too narrow limits. If the design must be within narrow limits, determine the parameters which are critical and expect the other parameters to vary.

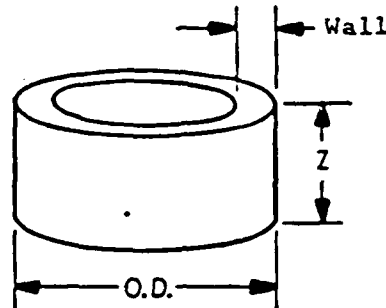
B6.2.5. Unless the transducer design uses idealized shapes, do not expect the nominal frequency constants and coupling factors in the standard to be applicable. When certain dimensions and dimensional ratios are used, they give rise to multiple mode couplings which can seriously alter the behavior of the ceramic element. In such cases empirical relationships may be required.

B6.2.6. On unusual design configurations, or where close tolerances on either electrical or mechanical parameters are required, consult with the ceramic manufacturers to determine realistic tolerances that can be maintained in production quantities before the specifications are finalized.

B6.3. Mechanical dimensions and tolerances. Typical variations in mechanical dimensions and tolerances are shown in Table BI for cylinders, tubes and rings; and Table BII for discs and plates. These Tables can be used as a guide in preparing specifications; however, the ceramic manufacturer should be consulted to determine the most cost-effective tolerances consistent with the application.

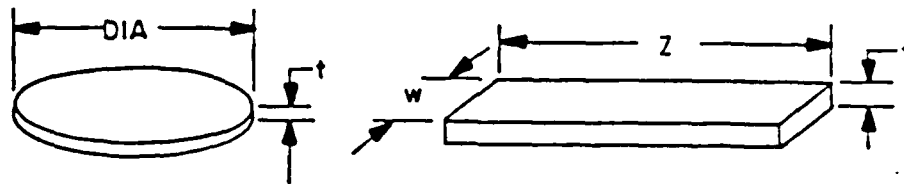
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Table BI. Typical Mechanical Tolerance Levels for Cylinders-Tubes-Rings.



CYLINDER-TUBE-RING (O.D.)		LEVEL A FULLY MACHINED (±)		LEVEL B MINIMAL MACHINING (±)		LEVEL C AS FIRED (±)	
INCH	MILLIMETER	INCH	MILLIMETER	INCH	MILLIMETER	INCH	MILLIMETER
0.250-0.500	6.35- 12.7	0.002	0.05	0.010	0.25	0.020	0.50
0.500-1.000	12.7 - 25.4	0.003	0.08	0.015	0.38	0.030	0.76
1.000-2.000	25.4 - 50.8	0.003	0.08	0.025	0.64	0.050	1.27
2.000-3.000	50.8 - 76.2	0.004	0.10	0.030	0.76	0.060	1.52
3.000-4.000	76.2 -101.6	0.004	0.10	0.050	1.27	0.090	2.29
4.000-6.000	101.6 -152.4	0.005	0.13	0.060	1.52	0.125	3.18
(Wall)							
0.020-0.031	0.51- 0.79	0.002	0.05	0.005	0.13	0.005	0.13
0.031-0.063	0.79- 1.60	0.002	0.05	0.005	0.13	0.010	0.25
0.063-0.100	1.60- 2.54	0.003	0.08	0.010	0.25	0.015	0.38
0.100-0.125	2.54- 3.12	0.003	0.08	0.015	0.38	0.020	0.51
0.125-0.250	3.17- 6.35	0.004	0.10	0.020	0.51	0.030	0.76
0.250-0.350	6.35- 8.89	0.004	0.10	0.030	0.76	0.040	1.02
0.350-0.500	8.89- 12.70	0.005	0.13	0.035	0.89	0.050	1.27
(Length Z)							
0.125-0.250	3.17- 6.35	0.002	0.05	0.005	0.13	0.010	0.25
0.250-2.000	6.35- 50.8	0.005	0.13	0.010	0.25	0.015	0.38
2.000-4.000	50.8 -101.6	0.010	0.25	0.015	0.38	0.020	0.51
4.000-6.000	101.6 -152.4	0.010	0.25	0.015	0.38	0.030	0.76
Squareness within: See Section B6.3		0.5 degree		1.5 degrees		2.5 degrees	

TABLE B-II. Typical Mechanical Tolerance Levels for Plates and Discs.



DISC (DIA)		LEVEL A		LEVEL B		LEVEL C	
PLATES (Z & w)		FULLY MACHINED (±)		MINIMAL MACHINING (±)		AS FIRED (±)	
INCH	MILLIMETER	INCH	MILLIMETER	INCH	MILLIMETER	INCH	MILLIMETER
0.125-1.500	3.2 - 38.1	0.003	±0.08	0.010	0.25	0.015	0.38
1.500-2.500	38.1 - 63.5	0.005	±0.13	0.015	0.38	0.020	0.50
2.500-3.500	63.5 - 88.9	0.005	±0.13	0.020	0.50	0.025	0.64
3.500-4.500	88.9 - 114.3	0.010	±0.25	0.025	0.64	0.040	1.02
4.500-6.000	114.3 - 152.4	0.010	±0.25	0.030	0.76	0.050	1.27
Disc & plate (thickness)(t)							
0.010-0.015	0.25- 0.38	0.001	±0.03	0.002	0.05	0.002	0.05
0.015-0.035	0.38- 0.89	0.001	±0.03	0.002	0.05	0.003	0.08
0.035-0.080	0.89- 2.03	0.002	±0.05	0.003	0.08	0.004	0.10
0.080-0.200	2.03- 5.08	0.003	±0.08	0.008	0.20	0.010	0.25
0.200-0.500	5.08- 12.70	0.004	±0.10	0.010	0.25	0.015	0.38
0.500-1.000	12.70- 25.40	0.005	±0.13	0.020	0.50	0.025	0.64
Parallel within:		0.001	0.03	0.003	0.08	0.007	0.18
Squareness within:		0.75 degrees		1.5 degrees		2.5 degrees	
Flatness:		0.001	0.03	0.003	0.08	Within thickness tolerance up to 1-in. dia and up to 0.080-in. thick. Within 0.005-in. above 0.080-in. thick.	
(max dia. for disc		per 1-	per 26-mm	per 1-	per 26-mm		
2 in. or plates		in. dia.	dia.	in. dia.	dia.		
with maximum							
dimensions of 2 in.							
in Z or w)							

NOTE: The flatness of ceramic elements with large diameter-to-thickness ratio is difficult to maintain. When discs or plates with dimensions larger than 50.8 mm (2.0 in.) are required the manufacturer should be consulted on the tolerance that can be maintained on production quantities.

B6.4. Ceramic element drawing. Figure B5 is a typical format which may be used in preparing the ceramic element drawing. It is not all inclusive. Other electrical parameters may be specified in place of or in addition to the parameters noted. The drawing should include requirements on the maximum size and number of open chips, closed chips or pits, etc., which are permitted. The drawing should be prepared in accordance with the data ordering document (see Appendix A).

B6.4.1. Open-chip criteria. The open-chip dimensions as shown in Figure B5 should be listed in 3 dimensions such as length, width, and depth. The number and maximum size of chips per ceramic edge should also be listed. The chip dimension should be in relation to the size and volume of the ceramic part. The chip size should not be large enough to affect the performance of the ceramic, nor should the chip size be infinitely small on a large ceramic piece. The specification of a very small chip could add considerable cost.

MATERIAL: TYPE _____

MATERIAL: TYPE _____ OF DOD-STD-XXX

CAPACITANCE _____ pF $\pm$ _____ pF (1 kHz)

MAXIMUM ADMITTANCE $Y_m \geq$ _____ S

OR MINIMUM IMPEDANCE $Z_m \leq$ _____ Ohms

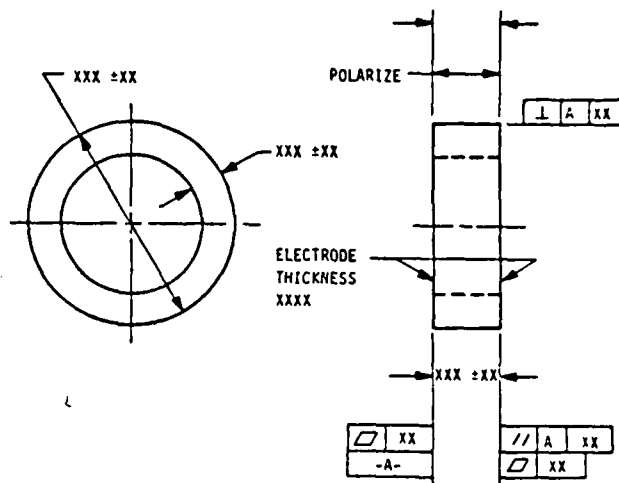
FREQUENCY f_m AT Y_m _____ Hz $\pm$ _____ Hz

MINIMUM ADMITTANCE $Y_n \leq$ _____ S

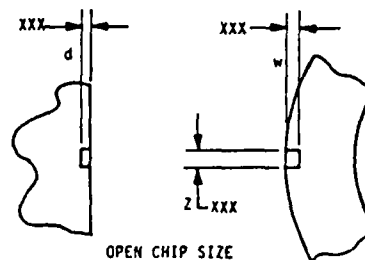
OR MAXIMUM IMPEDANCE $Z_n \geq$ _____ Ohms

FREQUENCY f_n AT Y_n _____ Hz $\pm$ _____ Hz

REFERENCE: ANSI PUBLICATION Y14.5



- NOTES:
1. CRACKS ARE/ARE NOT CAUSE FOR REJECTION
 2. CLOSED CHIPS ARE/ARE NOT CAUSE FOR REJECTION
 3. PITS ARE/ARE NOT CAUSE FOR REJECTION
(IN THE ABOVE 3 NOTES, THE QUANTITY AND SIZES OF ACCEPTABLE FLAWS SHALL BE SPECIFIED)
 4. SPECIFY EDGE BREAK/CHAMFER IF REQUIRED
 5. SPECIFY ELECTRODE MARGINS, OVERHANGS, AND VOIDS IF ALLOWED
 6. SPECIFY SURFACE FINISH AS REQUIRED
 7. SPECIFY POLARITY MARKING AS REQUIRED



MAXIMUM VALUE FOR (NUMBER AND SIZE) CHIPS ALLOWED. OTHER CHIPS SHALL NOT EXCEED
IN d, w, z .
ANYTHING LESS THAN _____ IS NOT
CONSIDERED A CHIP.

FIGURE B5 - Typical format for production ceramic elements - ring.

B6.5. Suggested ordering data or specification guide. Table BIII and Figure B5 present information which is typically required in specifying or describing a ceramic element. All necessary physical, mechanical, and piezoelectric requirements for a ceramic element should be described in a procurement specification and should include tolerances and test requirements. Over specifying the ceramic element will not only increase the cost but can result in incompatible requirements. **CAUTION:** *The statement "The ceramic shall meet all the requirements of DOD-STD-1376X(XX)" shall not be used to specify a specific ceramic element.* The user should carefully consider all of the possible requirements listed in Table BIII and specify clearly on the procurement document those which are pertinent to the ceramic element being procured.

Table BIII. Suggested Specification Guide for Ceramic Elements.

1. APPLICATION:

PROJECTOR _____ HYDROPHONE _____
 OTHER _____ (Description) _____

2. CERAMIC TYPE: I _____ II _____ III _____ IV _____ V _____
 VI _____ MODIFIED _____

PROPERTY: K_{33}^T _____ $\tan \delta$ _____ k_{eff} _____ k_p _____ N_l _____ N_p _____ Q_m _____ d_{33} _____ OTHER _____

NOMINAL
 VALUE
 REQUIRED

3. GEOMETRIC DESCRIPTION:

CYLINDER _____ DISC _____ PLATE _____ BAR _____ SPHERE _____ HEMISPHERE _____
 OTHER _____ (Description) _____

4. DIMENSIONAL REQUIREMENTS:

		TOLERANCE LEVEL			
		A	B	C	AA*
O.D.	_____	_____	_____	_____	_____
LENGTH	_____	_____	_____	_____	_____
WALL	_____	_____	_____	_____	_____
I.D.	_____	_____	_____	_____	_____
WIDTH	_____	_____	_____	_____	_____
THICKNESS	_____	_____	_____	_____	_____
FLATNESS	_____	_____	_____	_____	_____

(continued)

		TOLERANCE LEVEL			
		A	B	C	AA*
CONCENTRICITY	_____	_____	_____	_____	_____
PARALLELISM	_____	_____	_____	_____	_____
ROUNDNESS	_____	_____	_____	_____	_____
PERPENDICULARITY (squareness)	_____	_____	_____	_____	_____

* As specified in equipment specifications, see reference drawing.

5. OTHER SPECIAL REQUIREMENTS: _____

6. CHIPS AND PITS (Refer to Figures B1, B2, B3 and B5):
 MAXIMUM ALLOWABLE SIZE: _____
 MAXIMUM NUMBER ALLOWED: _____
 ANYTHING LESS THAN _____ IS NOT CONSIDERED A CHIP

7. ELECTRODE MATERIAL:
 SILVER _____ ELECTROLESS NICKEL _____ THICKNESS _____
 (consult with ceramic manufacturer)
 OTHER _____ (Specify) _____

ELECTRODE ADHERENCE REQUIREMENTS: _____

8. PLACEMENT OF ELECTRODES:
 MAJOR SURFACES _____ ENDS _____ O.D.-I.D. _____ STRIPES _____
 OTHER _____
 BORDERS _____ (Description) _____

9. ELECTRODE CONNECTION:

NONE _____ WIRE SIZE _____ (Describe wire type and stranding) _____

LOCATION AND SIZE OF ATTACHMENT _____

OTHER SPECIAL REQUIREMENTS _____

10. POLING DIRECTION:

RADIAL _____ LONGITUDINAL _____ TANGENTIAL _____ OTHER _____

(Description) _____

11. REFERENCE DWG. NO. OF CERAMIC ELEMENT: _____

12. ELECTRICAL PROPERTIES (10 DAYS AFTER POLING) LOW FIELD:

CAPACITANCE C^T _____ pF ($\pm$ _____ pF)
not required unless
DIELECTRIC LOSS FACTOR (MAX VALUE) $\tan \delta$ _____ different from value
specified in Table II.MAXIMUM ADMITTANCE MAGNITUDE $Y_m \gg$ _____ siemens (S)
OR MINIMUM IMPEDANCE $Z_m \ll$ _____ OhmsFREQUENCY OF MAXIMUM ADMITTANCE f_m _____ Hz ($\pm$ _____ Hz)
OR MINIMUM IMPEDANCEMINIMUM ADMITTANCE MAGNITUDE $Y_n \leq$ _____ siemens (S)
OR MAXIMUM IMPEDANCE $Z_n \geq$ _____ OhmsFREQUENCY OF MINIMUM ADMITTANCE f_n _____ Hz ($\pm$ _____ Hz)
OR MAXIMUM IMPEDANCE

13. CHANGE OF K_{33}^T WITH TEMPERATURE:

MAXIMUM CHANGE IN K_{33}^T , 0 TO 50°C, AS SPECIFIED IN TABLE (II)

DIFFERENT VALUE REQUIRED: _____ PERCENT AT _____ TEMPERATURE

14. HIGH FIELD MEASUREMENT REQUIRED: YES _____ NO _____

MAXIMUM CHANGE IN K_{33}^T AS SPECIFIED IN TABLE 3 (_____)

DIFFERENT VALUE REQUIRED: _____ PERCENT AT _____ KV/M

MAXIMUM DIELECTRIC LOSS FACTOR, AS SPECIFIED IN TABLE III (_____)

DIFFERENT VALUE REQUIRED: _____ PERCENT AT _____ KV/M

TEST FREQUENCY _____ HZ

15. DELIVERY DATA REQUIREMENT SUCH AS SETS OF ELECTRICAL MEASUREMENTS REQUIRED ON PRODUCTION CERAMIC ELEMENTS:

ONE (_____) TWO (_____) TIME BETWEEN MEASUREMENTS _____ DAYS

A.C. TIMS

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APPENDIX C

CONVERSION OF DISC PARAMETERS TO PERTINENT COEFFICIENTS OF OTHER MODES

C1. DIRECT CONVERSIONS*

Table II refers to properties obtained on discs with $d/t > 10$. These data lead directly to other coefficients as shown:

$$k_{31}^2 = [(1-\sigma^E)/2] k_p^2 \quad (C1)$$

$$1/s_{11}^E = [\pi^2 \rho N_p^2 (1-\sigma^E)] / \eta_1^2, \quad (C2)$$

where $\sigma^E = -S_{12}^E / S_{11}^E \approx 0.31$ and $\eta_1 \approx 2.05$.

$$d_{31} = k_{31} (\epsilon_{33}^T S_{11}^E)^{1/2}. \quad (C3)$$

$$g_{31} = d_{31} / \epsilon_{33}^T, \quad (C4)$$

where $\epsilon_{33}^T = K_{33}^T \epsilon_o, \quad (C5)$

and $\epsilon_o = 8.85 \times 10^{-12} \text{ F/m}. \quad (C6)$

In addition,

$$S_{11}^E = S_{11}^D / (1-k_{31}^2). \quad (C7)$$

* 61 IRE 14.S.1 IRE Standards on Piezoelectric Crystals: Measurements of Piezoelectric Ceramics, 1961 - July 1961.

C2. APPROXIMATION BETWEEN MODES*

Approximate** relationships between coefficients of transverse (31) and longitudinal (33) modes.

$$\begin{array}{lll} k_{33} \approx 2.0 & k_{31} & \\ d_{33} \approx 2.22 & d_{31} & \text{Types I, II, III, V, and VI} \\ S_{33}^E \approx 1.24 & S_{11}^E & \end{array}$$

$$\begin{array}{lll} k_{33} \approx 2.5 & k_{31} & \\ d_{33} \approx 2.60 & d_{31} & \text{Type IV} \\ S_{33}^E \approx 1.05 & S_{11}^E & \end{array}$$

and as in Eqs. (C7) and (C4)

$$S_{33}^E = S_{33}^D / (1 - k_{33}^2) \quad (C8)$$

and

$$g_{33} = d_{33} / \epsilon_{33}^T \quad (C9)$$

C3. CONVERSION OF FREQUENCY CONSTANTS OF DISC TO OTHER MODES

C3.1. Long slim bar. Transverse mode ($l > 3\lambda$, $l > 3t$)

$$N_1 \approx N_p / 1.364 \quad (C10)$$

C3.2. Thin-walled ring. Transverse (hoop) mode ($d > 5\lambda$, $d > 5t$)

$$N_H = (2/\pi) N_1 \quad (C11)$$

C3.3. Thin-walled spherical shell. ($d > 5t$)

$$N_{SS} \approx (3.4/\pi) N_1 \quad (C12)$$

* It should be noted here that D. Berlincourt Ref has shown that the degree of anisotropy is severely dependent on the thoroughness of poling; hence ratios of 33/31 constants apply only for typical nominal values - and even then are approximate. They are offered as a guide. For more accurate determinations, samples with appropriate boundary and poling conditions must be evaluated.

Ref D.A. Berlincourt, "Measurement of Piezoelectric Coupling in Odd Ceramic Shapes," Clevite Internal Report (TR-23), 1959.

C3.4. Square-plate "planar" mode. ($l > 10t$)

$$N_{SP} \approx 1.2 N_1 . \quad (C13)$$

Ref D. Berlincourt, "Variation of Electroelastic Constants of Polycrystalline Lead Titanate Zirconate with Thoroughness of Poling," J. Acoust. Soc. Am. 36(3), Mar 1964, pp. 515-520.