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MILITARY STANDARD

PIEZOELECTRIC CERAMIC MATERIAL AND MEASUREMENTS GUIDELINES FOR SONAR TRANSDUCERS

AMSC N/A FSC 5845

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

FOREWORD

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, SEA 03R42, Naval Sea Systems Command, 2531 Jefferson Davis Hwy, Arlington, VA 22242-5160, by using the self-addressed Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

3. 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 an acquisition 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 acquisition specification.

4. 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; for example, 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. Appendices attached provide clarification and assistance in the use of this standard.

2. APPLICABLE DOCUMENTS

2.1 Non-Government publications. The following document(s) form a part of this document to the extent specified herein. Unless otherwise specified, the issues of the documents which are DOD adopted are those listed in the issue of the DODISS cited in the solicitation. Unless otherwise specified, the issues of documents not listed in the DODISS are the issues of the documents cited in the solicitation (see 7.2).

AMERICAN NATIONAL STANDARD INSTITUTE (ANSI)
Y14.5M - Dimensioning and Tolerancing. (DoD adopted)

(Application for copies should be addressed to the American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036.)

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)
E 29 - Standard Practice for Using Significant Digits in Test Data to Determine Conformance Specifications.
E 380 - Standard Practice for the Use of the International System of Units (SI) (the Modernized Metric System).

(Application for copies should be addressed to the American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.)

INSTITUTE OF ELECTRICAL AND ELECTRONIC ENGINEERS (IEEE)
176 - Standard on Piezoelectricity.

(Application for copies should be addressed to the Institute of Electrical and Electronic Engineers, Inc., 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331.)

(Non-Government standards and other publications are normally available from the organizations that prepare or distribute the documents. These documents also may be available in or through libraries or other informational services.)

2.2 Order of precedence. In the event of a conflict between the text of this document and the references cited herein (except for related associated detail specifications, specifications, specification sheets or MS standards), the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

3. DEFINITIONS

3.1 Terminology. The terminology used in this standard is based on definitions given in IEEE 176 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 5.1.

3.1.2 Ceramic elements. Ceramic elements are those piezoelectric ceramic shapes (for example, bars, cylinders, discs, plates, rings, spheres, and hemi-spheres) 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 specification. See appendix A for general guidelines.

3.2 Units and symbols. The International System of Units (SI) as shown in ASTM 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 of 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 E 29, for indicating which places of figures are to be considered significant in specified limiting values.

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	meters/volt (m/V)
d_{33}	Piezoelectric constant, strain/field at constant stress	meters/volt (m/V)
ε_o	Permittivity of free space	8.8542×10^{-12} F/m
ε_{33}^T	Free permittivity of material (low frequency)	farads/meter (F/m)

TABLE I. Glossary, symbols, definitions, and units - Continued.

SYMBOL	DEFINITION	UNIT
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, $Q_m = Y_m / \left[\pi f_m C^T k_{eff}^2 \right]$	
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)

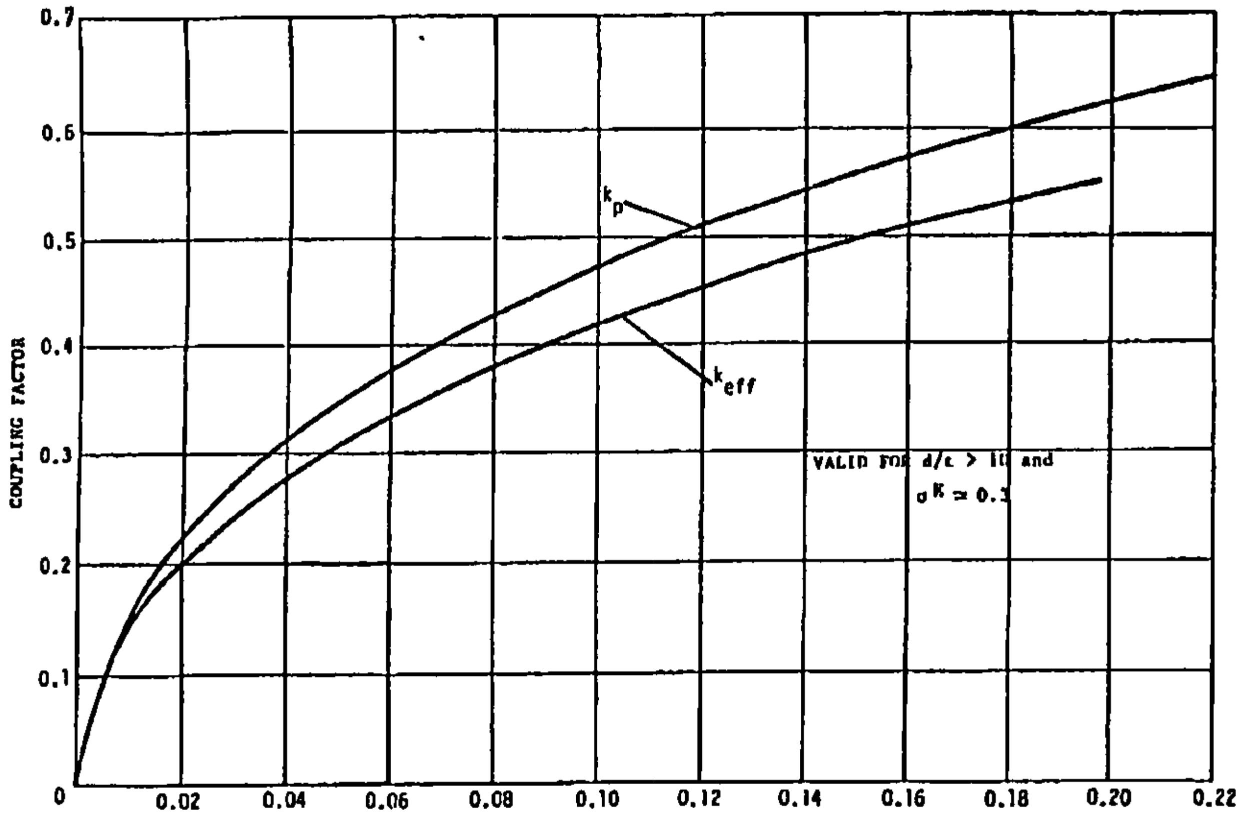


FIGURE 1. Planar and effective coupling factor as a function of $\Delta f/f_m$.
NOTE: Although $k_{eff}^2 = (f_n^2 - f_m^2)/f_n^2$, k_{eff} is plotted as a function of $\Delta f/f_m$ for convenience.

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 composition 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 4.1.1.1.

TABLE II. General properties and small signal values of ceramic standard types measured with the standard disc (10-day values).

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 ± 12.5%	-4.5 ± 2.0	1725 ± 12.5%	-1.5 ± 0.7	1025 ± 12.5%	-4.0 ± 1.5
Diel. Loss Factor	tan δ	≤ 0.006		≤ 0.020		≤ 0.004	
Planar Coup. Factor[2/]	k_p	0.58 ± 8.0%	-2.0 ± 1.0	0.60 ± 8.0%	-0.25 ± 0.15	0.50 ± 8.0%	-2.0 ± 1.0
Piezoelectric Coefficient[3/] 10^{-12} m/V	d_{33}	290 ± 15%		390 ± 15%		215 ± 15%	
Planar Freq. Constant Hz-m[4/]	N_p	2200 ± 8.0%	1.3 ± 0.8	1950 ± 8.0%	0.20 ± 0.10	2300 ± 8.0%	1.3 ± 0.8
Density 10^3 kg/m^3	ρ	≥ 7.45		≥ 7.60		≥ 7.45	
Mech. Qual. Factor[2,4/]	Q_m	≥ 500		≥ 75		≥ 800	
Percentage Change in K_{33}^T% 0° to 50°C[4/]		9.5 ± 3.0		25 ± 10		9.0 ± 3.0	
Approx. Curie Temp. °C		325		350		325	

See footnotes at end of table.

TABLE II. General properties and small signal values of ceramic standard types measured with the standard disc (10-day values) - Continued.

MATERIAL TYPES		IV		V		VI	
PROPERTY	SYMB	TYPICAL VALUES	AGING RATE 1/	TYPICAL VALUES	AGING RATE 1/	TYPICAL VALUES	AGING RATE 1/
Free Rel. Diel. Const.	K^T_{33}	1275 ± 12.5%	-1.50 ± 2.0	2500 ± 12.5%	-2.0 ± 1.0	3250 ± 12.5%	-2.0 ± 1.0
Diel. Loss Factor	tan δ	≤ 0.010		≤ 0.025		≤ 0.025	
Planar Coup. Factor 2/	k_p	0.30 ± 8.0%	-1.50 ± 0.50	0.63 ± 8.0%	-0.25 ± 0.2	0.64 ± 8.0%	-0.25 ± 0.2
Piezoelectric Coefficient 3/ 10^{-12} m/V	d_{33}	140 ± 15%		495 ± 15%		575 ± 15%	
Planar Freq. Constant Hz-m 4/	N_p	3150 ± 8.0%	0.40 ± 0.20	1950 ± 8.0%	0.35 ± 0.2	1940 ± 8.0%	0.35 ± 0.2
Density 10^3 kg/m^3	ρ	≥ 5.50		≥ 7.40		≥ 7.40	
Mech. Qual. Factor 5,6/	Q_m	≥ 400		≥ 70		≥ 65	
Percentage Change in K^T_{33}% 0° to 50°C 6/		5.0 ± 2.0		30 ± 10		40 ± 10	
Approx. Curie Temp. °C		115		240		180	

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 figure 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 of this document.

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^T_{33} 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 percent	ΔK_{33}^{T}	≤ 7.0	≤ 20.0	≤ 4.5	≤ 7.0	≤ 14.0
Value at indicated field	tan δ	≤ 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 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 4.1 through 4.1.1.1 shall be determined by measurements on standard test specimens manufactured as specified in 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 two flat surfaces of each disc shall be parallel and flat within plus or minus 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 specified in 6.2 through 6.10 shall be performed in accordance with the methods of IEEE 176.

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 and 25 degrees Celsius (°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 δ, 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 6.5. The K_{33}^T and tan δ 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 δ) 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 δ, 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 as specified in table II.

6.8 High-field measurements. After all other measurements are completed, the free relative dielectric constant, K^T_{33}, and the dielectric loss factor, tan δ, 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 (see 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^T_{33} and tan δ 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 gauges with certified accuracy to determine conformance to the requirements of 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 appendix B (40.).

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.

7. NOTES

(This section contains information of a general or explanatory nature that may be helpful, but is not mandatory.)

7.1 Intended use. This standard is intended to provide guidelines for designating piezoelectric ceramic material properties and measurements for use in sonar transducers. This document is not intended to replace an acquisition specification but does provide suggested acquisition practices and data requirements.

7.2 Issue of DODISS. When this standard is used in acquisition, the applicable issue of the DODISS must be cited in the solicitation (see 2.1).

7.3 Subject term (key word) listing.

Dielectric properties
Electrodes
Standard ceramic types
Standard disc

7.4 Changes from previous issue. Marginal notations are not used in this revision to identify changes with respect to the previous issue due to the extensiveness of the changes.

Preparing activity:
Navy - SH
(Project 5845-N111)

APPENDIX A

SUGGESTED ACQUISITION PRACTICES AND DATA REQUIREMENTS

10. GENERAL

10.1 Scope. When this standard is used in the preparation of an acquisition specification or drawing for piezoelectric elements for sonar transducers, it is recommended that the following requirements or some modification thereof be included in the acquisition specifications. This appendix is not a mandatory part of the standard. The information contained herein is intended for guidance only.

20. APPLICABLE DOCUMENTS

This section is not applicable to this appendix.

30. DATA

30.1 Consideration of data requirements. When a commodity standard is prepared, and data requirements may need to be considered for inclusion on the Contract Data Requirements List (DD Form 1423), the following paragraph should be inserted in section 6 of the standard:

"6.3 Consideration of data requirements. The following data requirements should be considered when this standard is applied on a contract. The applicable Data Item Descriptions (DID's) should be reviewed in conjunction with the specific acquisition to ensure that only essential data are requested/provided and that the DID's are tailored to reflect the requirements of the specific acquisition. To ensure correct contractual application of the data requirements, a Contract Data Requirements List (DD Form 1423) must be prepared to obtain the data, except where DOD FAR Supplement 27.475-1 exempts the requirement for a DD Form 1423.

Reference Paragraph	DID Number	DID Title	Suggested Tailoring
(See 3.1.3 and appendix B (60.4 and figure 7))	DI-DRPR-81000	Product drawings and associated lists	----
(See 30.2)	DI-MISC-80678	Certification/data report	10.3.1 (or 10.3.2) does not apply
(See 30.4)	DI-QCIC-81110	Inspection and test plan	----

The above DID's were those cleared as of the date of this standard. The current issue of DOD 5010.12-L, Acquisition Management Systems and Data Requirements Control List (AMSDL), must be researched to ensure that only current, cleared DID's are cited on the DD Form 1423."

30.2 Certification of manufacturers. A prospective piezoelectric ceramic manufacturer must 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.

30.3 Prior certification. A ceramic contractor who has previously manufactured the specific ceramic types must 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 as specified in 30.2. The requirements for first-article and production ceramic elements are specified in the individual equipment specification.

30.4 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 must 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 activity.

APPENDIX B

GUIDANCE IN SELECTION AND SPECIFICATION OF PIEZOELECTRIC CERAMIC

10. GENERAL

10.1 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. This appendix is not a mandatory part of the standard. The information contained herein is intended for guidance only.

20. APPLICABLE DOCUMENTS

This section is not applicable to this appendix.

30. MECHANICAL DEFINITIONS

30.1 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.

30.1.1 Open chips. Flaws at the intersection of two surfaces from which a fragment of the ceramic is missing (see figure 2).

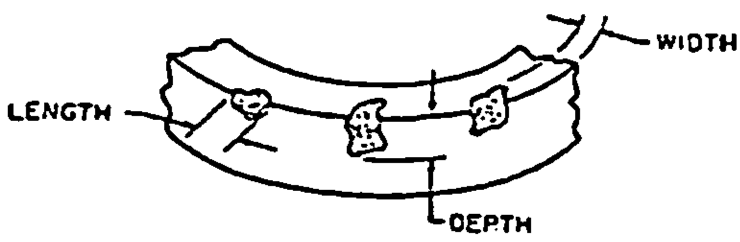


FIGURE 2. Open chips.

30.1.2 Closed chips. Flaws in the ceramic consisting of chips that are not completely removed (see figure 3).

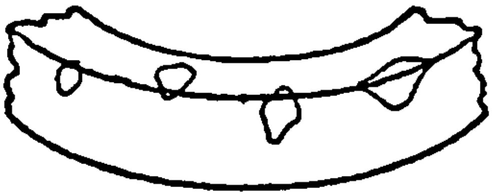


FIGURE 3. Closed chips.

30.1.3 Pits. A pit is an open cavity on any surface (see figure 4).

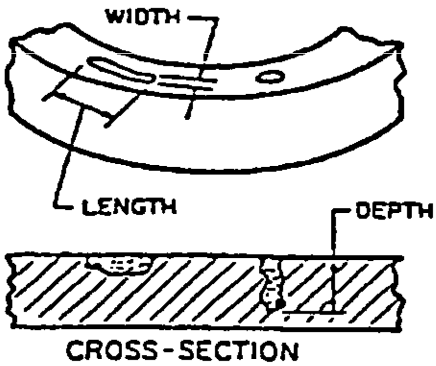


FIGURE 4. Pits.

30.1.4 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.

40. ELECTRODES

40.1 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.

40.2 Electrode adhesion tests. The two 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.

40.3 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.

40.3.1 Suggested equipment and material.

(a) Soldering iron - 20 watts (approximately) with small pencil tip (2-millimeter (5/64-inch) diameter, preferably a temperature-controlled tip of 288°C (550 degrees Fahrenheit (°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.

40.3.2 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.

40.3.3 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 be not 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.

40.3.4 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 is considered invalid and must be repeated.

NOTE: Exceptions to tensile test: The adhesion test outlined in 40.3 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 40.4).

40.4 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.

40.4.1 Standard test specimen procedure. To test the specimen, one electroded surface of all test specimens should be cleaned with a solvent such as Isopropyl Alcohol. 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), is pressed firmly across the diameter of the electrode. The tape should be in contact with the surface at a temperature between 20 and 30°C and RH of 60 percent or less. One end of the tape should 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 1.59-millimeter (1/16-inch) diameter of the electrode surface with the tape is considered a failure to pass the test. More than two such failures out of 10 test specimens is unacceptable. (Note: This test applies only to the standard test specimens.)

40.4.2 Ceramic elements procedure. The test procedure and the acceptance requirements should be specified in the individual equipment or ceramic element specification.

50. ELECTRICAL DEFINITIONS

50.1 See table I.

50.2 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 5. Additional information can be found in the references.

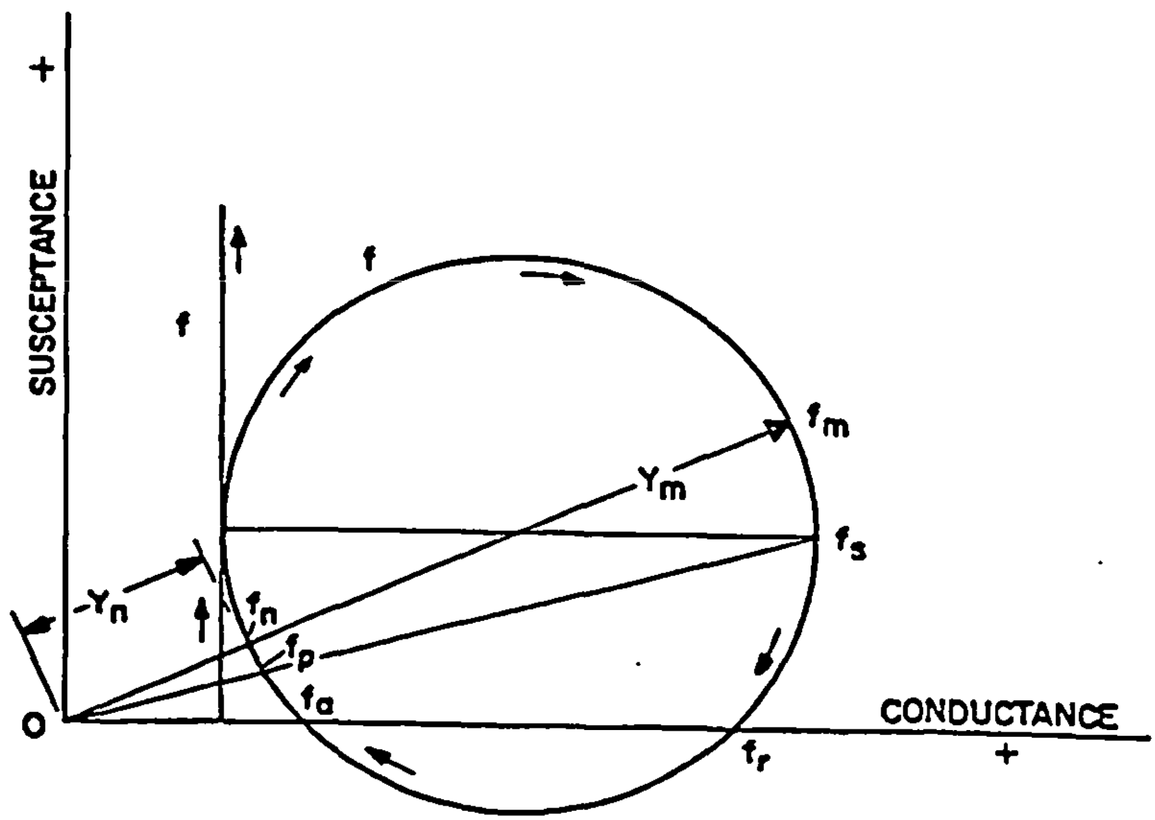


FIGURE 5. Vector admittance diagram of a piezoelectric resonator.

60. GENERAL REQUIREMENTS

60.1 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.

60.1.1 Note that silicone oil should not be used during poling or in the processing or manufacturing of ceramics.

60.2 Guidelines for specifications pertaining to the transducer design.

60.2.1 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 (such as, I, II, III, and so forth) the material parameters specified will take precedence.

60.2.2 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.

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

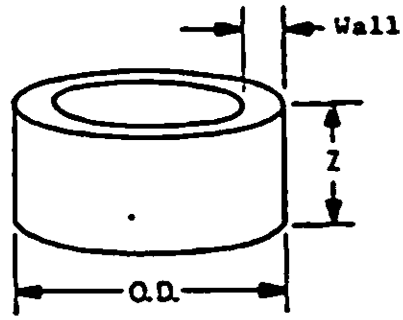
60.2.4 Do not restrictively specify both dimensions and piezoelectric properties within too narrow limits. If the design must be within narrow limits, determine the parameters which are critical and expect the other parameters to vary.

60.2.5 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.

60.2.6 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.

60.3 Mechanical dimensions and tolerances. Typical variations in mechanical dimensions and tolerances are shown in table IV for cylinders, tubes, and rings; and table V 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.

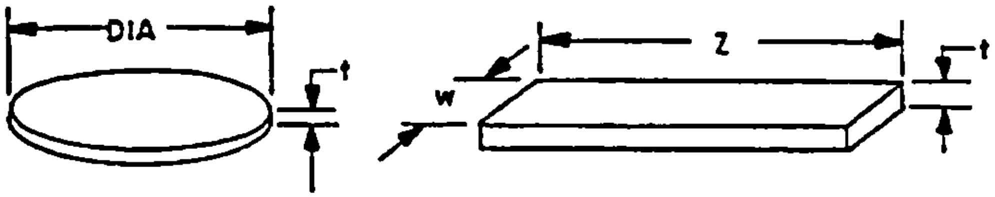
TABLE IV. Typical mechanical tolerance levels for cylinders-tubes-rings.



CYLINDER-TUBE-RING (o.d.) INCH	MILLIMETER	LEVEL A FULLY MACHINED (±) INCH	MILLIMETER	LEVEL B MINIMAL MACHINING (±) INCH	MILLIMETER	LEVEL C AS FIRED (±) 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	0.050	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:		0.5 degree		1.5 degrees		2.5 degrees	

See 60.3

TABLE V. Typical mechanical tolerance levels for plates and discs.



DISC (DIA) PLATES (Z & w) INCH	MILLIMETER	LEVEL A FULLY MACHINED (±) INCH	MILLIMETER	LEVEL B MINIMAL MACHINING (±) INCH	MILLIMETER	LEVEL C AS FIRED (±) 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: (max dia. for disc 2 in or plates with maximum dimensions of 2 in. in Z or w)		0.001 per 1-in. dia.	0.03 per 26-mm dia.	0.003 per 1-in. dia.	0.08 per 26-mm dia.	Within thickness tolerance up to 1-in. dia and up to 0.080-in thick. Within 0.005-in. above 0.080-in. thick.	

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.

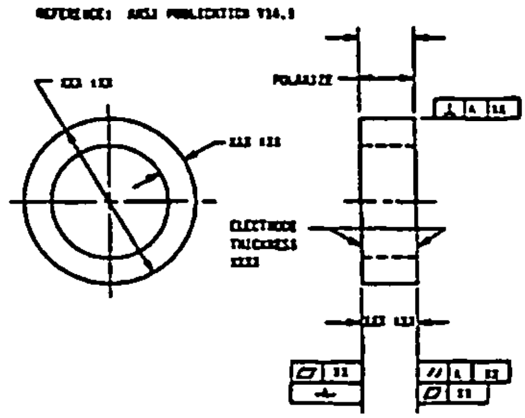
60.4 Ceramic element drawing. Figure 6 is a typical format which may be used in preparing the ceramic element drawing. It is not all inclusive. Other electrical parameters may be specified in place of or in addition to the parameters noted. The drawing should include requirements on the maximum size and number of open chips, closed chips or pits, and so forth, which are permitted. The drawing should be prepared in accordance with the data ordering document (see appendix A).

60.4.1 Open-chip criteria. The open-chip dimensions as shown on figure 6 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 ± ________ pF (1 kHz)
MAXIMUM ADMITTANCE Y_m ≤ ________ S
OR MINIMUM IMPEDANCE Z_m ≤ ________ Ohms
FREQUENCY f_m AT Y_m ________ Hz ± ________ Hz

MINIMUM ADMITTANCE Y_n ≤ ________ S
OR MAXIMUM IMPEDANCE Z_n ________ Ohms
FREQUENCY f_n AT Y_n ________ Hz ± ________ Hz



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 ACCEPTANCE 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.

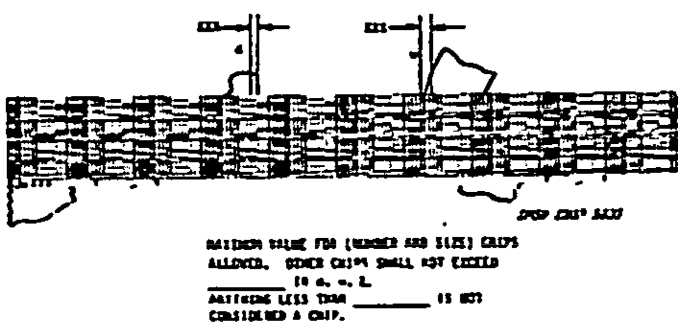


FIGURE 6. Typical format for production ceramic elements - ring.

60.5 Suggested ordering data or specification guide. Figures 6 and 7 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 an acquisition specification and should include tolerances and test requirements. Overspecifying 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)" should not be used to specify a specific ceramic element. The user should carefully consider all of the possible requirements listed on figure 7 and specify clearly on the acquisition document those which are pertinent to the ceramic element being acquired.

1. **APPLICATION:**

PROJECTOR ____________________ HYDROPHONE ____________________

OTHER ____________________ (Description) ____________________

____

2. **CERAMIC TYPE:** I ______ II ______ III ______ IV ______ V ______

VI ______ MODIFIED ______

PROPERTY: K^T_{33}___ tan δ___ k_{eff}___ k_p___ N_1___ 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)

FIGURE 7. Suggested specification guide for ceramic elements.

	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) ________________

____

FIGURE 7. Suggested specification guide for ceramic elements - Continued.

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 (± ________ pF) not required unless different from value specified in Table II
DIELECTRIC LOSS FACTOR (MAX VALUE)	$\tan \delta$ ______	
MAXIMUM ADMITTANCE MAGNITUDE OR MINIMUM IMPEDANCE	$Y_m \geq$ ______ $Z_m \leq$ ______	siemens (S) Ohms
FREQUENCY OF MAXIMUM ADMITTANCE OR MINIMUM IMPEDANCE	f_m ________	Hz (± ________ Hz)
MINIMUM ADMITTANCE MAGNITUDE OR MAXIMUM IMPEDANCE	$Y_n \leq$ ______ $Z_n \geq$ ______	siemens (S) Ohms
FREQUENCY OF MINIMUM ADMITTANCE	f_n ________	Hz (± ________ Hz)

FIGURE 7. Suggested specification guide for ceramic elements - Continued.

13. **CHANGE OF K^T_{33} WITH TEMPERATURE:**

MAXIMUM CHANGE IN K^T_{33}, 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^T_{33} AS SPECIFIED IN TABLE III ( )

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

FIGURE 7. Suggested specification guide for ceramic elements - Continued.

APPENDIX C

CONVERSION OF DISC PARAMETERS TO PERTINENT COEFFICIENTS OF OTHER MODES

10. GENERAL

10.1 Scope. This appendix provides methods for conversion of disc parameters to pertinent coefficients of other modes. This appendix is not a mandatory part of the standard. The information contained herein is intended for guidance only.

20. APPLICABLE DOCUMENTS

This section is not applicable to this appendix.

30. DIRECT CONVERSIONS*

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

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

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

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

$$d_{31} = k_{31}\ (\varepsilon_{33}^T\ S_{11}^E)^{1/2} \qquad \text{(C3)}$$

$$g_{31} = d_{31}/\varepsilon_{33}^T\ , \qquad \text{(C4)}$$

where

$$\varepsilon_{33}^T = K_{33}^T\ \varepsilon_o\ , \qquad \text{(C5)}$$

and

$$\varepsilon_o = 8.85 \times 10^{-12}\ \text{F/m}. \qquad \text{(C6)}$$

In addition,

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

---

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

40. APPROXIMATION BETWEEN MODES*

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

$$k_{33} = 2.0 \quad k_{31}$$

$$d_{33} = 2.22 \quad d_{31} \qquad \text{Types I, II, III, V, and VI}$$

$$s^{E}_{33} = 1.24 \quad s^{E}_{11}$$

$$k_{33} = 2.5 \quad k_{31}$$

$$d_{33} = 2.60 \quad d_{31} \qquad \text{Type IV}$$

$$s^{E}_{33} = 1.05 \quad s^{E}_{11}$$

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

$$s^{E}_{33} = s^{D}_{33}/(1-k_{33}{}^{2}) \qquad \text{(C8)}$$

and

$$g_{33} = d_{33}/\varepsilon^{T}_{33} \quad . \qquad \text{(C9)}$$

50. CONVERSION OF FREQUENCY CONSTANTS OF DISC TO OTHER MODES

50.1 Long slim bar. Transverse mode $(\ell > 3\omega,\ \ell > 3t)$

$$N_1 = N_p/1,364 \quad , \qquad \text{(C10)}$$

50.2 Thin-walled ring. Transverse (hoop) mode $(d > 5\ell,\ d > 5t)$

$$N_H = (2/\pi)\ N_1 \quad . \qquad \text{(C11)}$$

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

$$N_{\hat{s}\hat{s}} = (3.4/\pi)\ N_1 \quad . \qquad \text{(C12)}$$

** 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 ratio 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.

50.4 Square-plate "planar" mode. (ℓ>10t)

$$N_{SP} = 1.2 \; N_1 \quad . \tag{C13}$$

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.

STANDARDIZATION DOCUMENT IMPROVEMENT PROPOSAL

INSTRUCTIONS

1. The preparing activity must complete blocks 1, 2, 3, and 8. In block 1, both the comment number and revision letter should be given.
2. The submitter of this form must complete blocks 4, 5, 6, and 7.
3. The preparing activity must provide a reply within 30 days from receipt of this form.

NOTE: This form may not be used to request copies of documents, nor to request waivers, or clarification of requirements on current contracts. Comments submitted on this form do not constitute or imply authorization to waive any portion of the referenced document(s) or to amend contractual requirements.

I RECOMMEND A CHANGE:	1. DOCUMENT NUMBER MIL-STD-1376B(SH)	2. DOCUMENT DATE (YYMMDD) 950224

3. DOCUMENT TITLE
PIEZOELECTRICAL CERAMIC MATERIAL AND MEASUREMENTS GUIDELINES FOR SONAR TRANSDUCERS

4. NATURE OF CHANGE (identity paragraph number and include proposed rewrite, if possible. Attach extra sheets as needed.)

5. REASON FOR RECOMMENDATION

6. SUBMITTER

a. NAME (Last, First, Middle Initial)	b. ORGANIZATION	
c. ADDRESS (include Zip Code)	d. TELEPHONE (Include Area Code) (1) Commercial (2) DSN (if applicable)	7. DATE SUBMITTED (YYMMDD)

8. PREPARING ACTIVITY

a. NAME Technical Point of Contact (TPOC) MR. Y. SODHI, PMS42583 ADDRESS ALL CORRESPONDENCE AS FOLLOWS:	b. TELEPHONE (Include Area Code) (1) Commercial: DSN: TPOC: 703-602-7892 8-332-7892
c. ADDRESS (Include Zip Code) COMMANDER, NAVAL SEA SYSTEMS COMMAND ATTN: SEA 03R42 2531 JEFFERSON DAVIS HIGHWAY ARLINGTON, VA 22242-5160	IF YOU DO NOT RECEIVE A REPLY WITHIN 45 DAYS, CONTACT: Defense Quality and Standardization Office 5203 Leesburg Pike, Suite 1403 Falls Church, VA 22041-3466 Telephone 703-756-2340 DSN 289-2340