METRIC

DOD-STD-1376A(SH)
28 February 1984
SUPERSEDING
MIL-STD-1376(SHIPS)
21 December 1970

MILITARY STANDARD

PIEZOELECTRIC CERAMIC FOR SONAR TRANSDUCERS (HYDROPHONES AND PROJECTORS)

FSC 5845

DEPARTMENT OF DEFENSE
Washington, DC 20362

Piezoelectric Ceramic for Sonar Transducers

DOD-STD-1376A(SH)(METRIC)

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 may be of use in improving this document should be addressed to: Commander, Naval Sea Systems Command, SEA 55Z3, 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 covers a system of designating piezoelectric ceramic materials by type, to define certain minimum and maximum properties for these types, and to aid in the choice of material selection. Part (A) should be referenced to define the type material required for hydrophones. Part (B) should be referenced to define the type material required for projectors.

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 only be determined by measurement on specific geometric shapes (for example, thin discs and rings) and that the 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 only be determined from actual measurements on the specific ceramic material and shape.

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FIGURES

TABLES

1. SCOPE

1.1 Scope. This standard covers the types of piezoelectric ceramic materials required to manufacture sonar transducers for the Naval service. This standard covers the requirements for the ceramic compositions for four types based on standard test specimens and the procedure to certify piezoelectric ceramic manufacturers.

1.2 Classification. The standard ceramic types shall be of the following types:

Type I. Hard lead zirconate titanate with a Curie point equal to or greater than 310 degrees Celsius (°C).

Type II. Soft lead zirconate titanate with a Curie point equal to or greater than 330°C.

Type III. Very hard lead zirconate titanate with a Curie point equal to or greater than 290°C.

Type IV. Barium titanate with nominal additives of 5 percent calcium titanate and 0.5 percent cobalt carbonate with a Curie point equal to or greater than 100°C.

2. REFERENCED DOCUMENTS

2.1 Issue of documents. Not applicable.

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.

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

(Application for copies should be addressed to the American National Standards Institute, 1430 Broadway, New York, NY 10018.)

ASTM
E 380 - Metric Practice. (DoD adopted)

(Application for copies should be addressed to the ASTM, 1916 Race Street, Philadelphia, PA 19103.)

INSTITUTE OF ELECTRICAL AND ELECTRONIC ENGINEERS (IEEE)
IEEE 176 - 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 except as follows:

3.1.1 Standard test specimens. The standard test specimens intended for verification of the material composition for hydrophones as defined in part (A) of this standard will be in the form of thin discs as specified in 5.1 through 5.3. The standard test specimens intended for verification of the material compositions for projectors as defined in part (B) of this standard will be in the form of rings as specified in 5.2 through 5.2.3.

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

3.1.3 Individual equipment specifications. Drawings and specifications which describe ceramic elements shall be as specified in 3.1.2 and in accordance with the data ordering document (see appendix A).

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 or component on an engineering drawing shall be in accordance with ANSI Y14.5.

TABLE I. Glossary, symbols, definitions and units.

Symbol	Definition	Unit
C^T	Free capacitance (low frequency)	farad (F)
D_m	Mean diameter	meter (m)
ε_o	Permittivity of free space	8.8542×10^{-12} farads/meter
ε_{33}^T	Free permittivity of material (low frequency)	farads/meter (F/m)
E	Applied electric field	kilovolt/meter (kV/m)
f_m	Frequency of maximum admittance (minimum impedance)	hertz (Hz)
f_n	Frequency of minimum admittance (maximum impedence)	hertz (Hz)
K_{33}^T	Free relative dielectric constant $= \varepsilon_{33}^T/\varepsilon_o$	
k_{eff}^2	Effective coupling factor, $k_{eff}^2 = (f_n^2 - f_m^2)/f_n^2$	
k_p	Planar coupling factor (see figure 1)	
ℓ	Length	meter (m)
N_1	Frequency constant for a ring, $N_1 = (f_m \pi D_m)/2$	hertz-meter (Hz.m)
N_p	Frequency constant planar mode disc, $N_p = (f_m.\text{Diam})$	hertz-meter (Hz.m)
Q_m	Mechanical quality factor, $Q_m = Y_m/(2\pi f_m C^T k^2{}_{eff})$	
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 at constant electric field	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)

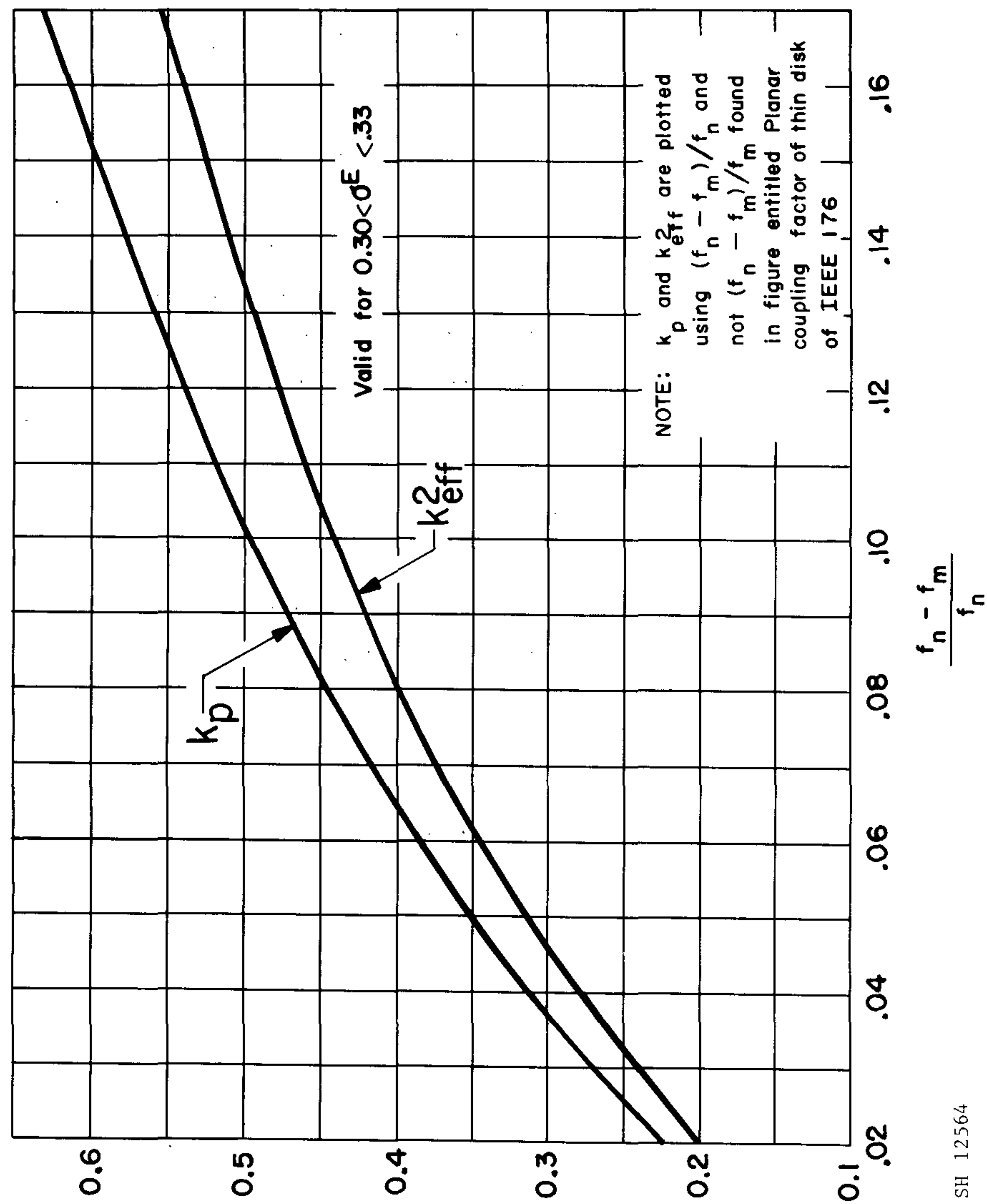

FIGURE 1. Planar and effective coupling factor of thin disc.

4. GENERAL REQUIREMENTS

4.1 Standard ceramic types. The standard ceramic types shall be defined as follows:

(a) Type I. Hard lead zirconate titanate with a Curie point equal to or greater than 310°C.
(b) Type II. Soft lead zirconate titanate with a Curie point equal to or greater than 330°C.
(c) Type III. Very hard lead zirconate titanate with a Curie point equal to or greater than 290°C.
(d) Type IV. Barium titanate with nominal additives of 5 percent calcium titanate and 0.5 percent cobalt carbonate with a Curie point equal to or greater than 100°C.

NOTE: Standard test specimens shall be required only in acquisitions when a ceramic contractor must demonstrate the ability to produce the specific type(s) and is not currently certified as specified in 4.1.1.2.

4.1.1 Standard ceramic type compositions. The standard ceramic types to be used in sonar hydrophone receivers shall have the properties shown in table II. Types to be used in sonar projectors shall have the properties shown in table III and table IV. The properties shall be measured on standard test specimens as specified in part (A) and part (B). Lead zirconate titanate compositions shall have a nominal zirconate/titanate ratio of 53/47 modified with additives to meet the requirements of tables II, III or IV (where applicable), except as specified in 4.1.1.1.

4.1.1.1 Modified compositions. Deviations from the properties shown in tables II, III and IV for the standard ceramic types specified in 4.1 and 4.1.1 will be acceptable when required by the individual equipment specification.

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

(a) Manufacture 10 or more standard test specimens of the specific type(s).
(b) Perform all tests specified herein for the particular application (hydrophone or projectors).
(c) Provide the test data to the contracting activity for examination and approval in accordance with the data ordering document (see appendix A).
(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.

TABLE II. General properties and small signal values of hydrophone ceramic standard types measured with the standard disc.

Property		Material types											
		I			II			III			IV		
		10-day value Min	10-day value Max	Aging1/ rate percent	10-day value Min	10-day value Max	Aging1/ rate percent	10-day value Min	10-day value Max	Aging1/ rate percent	10-day value Min	10-day value Max	Aging1/ rate percent
Free relative dielectric constant	K^T_{33}	1100	1400	-6 max -3 min	1575	1875	-1.5 max	950	1150	-5 max -2.0 min	1100	1400	-2
Dielectric loss factor	tan δ	---	0.006	---	---	0.02	---	---	0.004	---	---	0.008	---
Piezoelectric coupling2/ factor (planar)	k_p	0.52	0.60	6/ -2.5	0.54	0.62	-0.3	0.47	0.55	-2	0.28	0.33	-2
Frequency3/ constant (Hz-m)	N_p	1990	2430	6/ +2.5	1795	2190	+0.25	2035	2480	+1.0	2870	3500	+0.5
Density kg/m^3	ρ	7500	---	---	7600	---	---	7500	---	---	5550	---	---
Mechanical4/5/ quality factor	Q_m	500	---	---	---	---	---	800	---	---	400	---	---
Percentage5/ change in K^T_{33} 0 to 50°C		---	10	---	---	30	---	---	10	---	---	6	---

1/ The aging rate is the maximum and minimum (where specified) permitted change (percent) in properties in the period up to 100 days after poling using the 10 day value as the base.

2/ The planar coupling factor, k_p, will be determined from figure 1, 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 $\leq$ 0.01 V/mm.

3/ Planar mode disc $N_p = (f_m \cdot \text{Diam})$.

4/ The mechanical quality factor, Q_m, defined by $Q_m = Y_m/(2\pi f_m C^T k^2_{eff})$ where C^T is the small signal capacitance measured at 1 kHz, Y_m is the maximum admittance measured at f_m. Value for type II material is very low and is therefore not specified.

5/ 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.

6/ Stated as typical value.

TABLE III. General properties and small signal values of projector ceramic standard types measured with a standard ring.

Property		Material types											
		I			II 5/			III			IV		
		10-day value		Aging 1/ rate percent	10-day value		Aging 1/ rate percent	10-day value		Aging 1/ rate percent	10-day value		Aging 1/ rate percent
		Min	Max		Min	Max		Min	Max		Min	Max	
Free relative dielectric constant	K^T_{33}	1100	1400	-6 max -3 min	1575	1875	-1.5	950	1150	-5 max -2.0 min	1100	1400	-2
Dielectric loss factor	tan δ	---	0.006	---	---	0.02	---	---	0.004	---	---	0.008	---
Piezoelectric 2/ coupling factor (effective)	k^2_{eff}	0.31	0.36	7/ -2.5	0.32	0.38	0.3	0.27	0.33	-2	0.145	0.20	-2
Frequency 3/ constant (Hz-m)	N_1	1500	1750	7/ +2.5	1300	1550	+.25	1550	1880	+1.0	2200	2500	0.5
Density kg/m³	ρ	7500	---	---	7600	---	---	7500	---	---	5550	---	---
Mechanical 4/ 6/ quality factor	Q_m	500	---	---	---	---	---	800	---	---	400	---	---
Percentage change 6/ in K^T_{33} 0 to 50°C		---	10	---	---	30	---	---	10	---	---	6	---

1/ The aging rate is the maximum and minimum (where specified) permitted change (percent) in properties in the period up to 100 days after poling using the 10 day value as the base.
2/ The effective coupling factor is defined by $k^2_{eff} = (f^2_n - f^2_m)/f^2_n$ where f_n is frequency of minimum admittance and f_m is the frequency of maximum admittance; f_m to be measured at fields $\leq$ 0.01 V/mm.
3/ The frequency constant N_1 for a thin ring is defined as $N_1 = (f_m \pi D_m)/2$, where D_m is the mean diameter.
4/ The mechanical quality factor Q_m defined as $Q_m = Y_m/(2\pi f_m C^T k^2_{eff})$ where C^T is the small signal capacitance measured at 1 kHz, Y_m is the maximum admittance magnitude measured at f_m. Value for type II material is very low and is therefore not specified.
5/ Type II is not recommended for use in projector applications.
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.
7/ Stated as typical value.

TABLE IV. Large signal dielectric properties of projector ceramic standard types (measured in air).

Property		Material type				
		I		III	IV	
Applied electric field kV/m (rms)	E	200	400	400	150	300
Max change in K_{33}^T (percent) above small signal value (0.1 to 1.0 V/mm)	ΔK_{33}^T	5	18	4.0	6	12
Max dielectric loss factor	tan δ	0.02	0.04	0.01	0.015	0.03

NOTE: Measurements at any frequency in the range 60 Hz to 2 kHz.

4.1.1.3 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 shall be required to be recertified in accordance with 4.1.1.2.

4.2 Requirements.

4.2.1 Standard test specimens. Conformance with 4.1 through 4.1.1.1 shall be determined by measurements on standard test specimens manufactured in accordance with 5.1 through 5.1.3 for discs and 5.2 through 5.2.3 for rings. The detailed requirements for these specimens are specified in 5.1 and 5.2, part (A) and part (B) respectively. Not less than 10 test specimens shall be manufactured for each ceramic type being tested. The requirements for first article and production ceramic elements shall be specified in the individual equipment specification.

4.2.2 Electrical measurements. The electrical measurements shall be made at a temperature between 20 and 25°C. Each test specimen shall be stored between these temperatures for at least 24 hours prior to the measurements. The temperature at which the measurements are made shall be recorded.

4.2.3 Workmanship. The standard test specimens shall meet all requirements specified herein. The specimens shall be clean and dry.

4.2.4 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.

4.2.5 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.

5. DETAILED REQUIREMENTS

5.1 Part A - Hydrophone applications.

5.1.1 Dimensions and finish of standard test specimens. The standard test specimens for verification of the compositions for hydrophones shall be ceramic discs with a surface finish before electroding not to exceed 1.60 micrometers (63 microinch (μinch)). Each surface shall be flat within 0.05 millimeter (mm) (.002 inch) and the two flat surfaces of each disc shall be parallel within 0.05 mm (.002 inch). The dimensions of the finished poled discs shall be as follows.

Diameter 31.8 ± 0.15 mm (1.25 ± 0.006 inches)
Thickness 2.5 ± 0.13 mm (0.10 ± 0.005 inch)

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

5.1.1.1.1 Adherence. The electrode adherence shall meet the test specified in 5.1.4.1.7.

5.1.2 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 +, with a nonconducting ink. 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.

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

5.1.4 Requirements.

5.1.4.1 Examination and tests for standard test disc specimens.

5.1.4.1.1 Method. The measurements of 5.1.4.1.2 through 5.1.4.1.7 shall be performed in accordance with the methods of IEEE 176.

5.1.4.1.2 Density. The density, ρ, of each test specimen shall be determined by weight and dimensions or 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.

5.1.4.1.3 Small signal properties. The small signal values of the free relative dielectric constant, K^T_{33}, the dielectric loss factor, tan δ, the planar coupling factor, k_p, and the planar mode frequency constant, N_p, of each test specimen shall be measured three times in the period between 10 and 100 days after poling. K^T_{33} and tan δ shall be measured at 1 kilohertz (kHz).

5.1.4.1.3.1 Time of measurement. The first set of measurements of K^T_{33}, tan δ, k_p and N_p shall be made within 20 days after the poling, the second set approximately 45 days after poling, and the third set approximately 100 days after poling. The three sets of data shall be plotted against the logarithm of the time in days since poling and the values at 10 and 100 days shall be determined by extrapolation using a best fit straight line. The 10-day values and the aging rates (excluding the rate for tan δ) for each time decade from 10 to 100 days shall fall within the limits of table II.

5.1.4.1.4 Quality factor, Q_m, and temperature characteristics of K^T_{33}. After the final set of small signal measurements of K^T_{33}, 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^T_{33} shall be measured in that order and the corresponding values shall fall within the limits of table II. The percentage change in K^T_{33} 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 electrodes 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.

5.1.4.1.5 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 5.1.

5.1.4.1.6 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.

5.1.4.1.7 Electrode adherence. 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 at least 25 mm (nominal 1 inch) wide and 70 mm (2.76 inches) long with an adhesion greater than 50 ounce/inch (oz/in) 13.9 newton (N/25 mm) width, shall be pressed firmly across the diameter of the electrode. The tape shall remain in contact with the surface for at least 24 hours at a temperature between 20 and 25°C. One end of the tape shall then be lifted normal to the electroded surface forming a 90 degree angle. Continue to pull the tape until it is removed. The removal of any portion of the electroded surface with the tape shall be considered a failure to pass this test. More than two such failures out of ten test specimens is unacceptable. (Note: This test applies only to the standard test specimens. The test required for first article and production ceramic elements shall be specified in the individual equipment or ceramic element specification.)

5.2 Part B - Sonar projector application.

5.2.1 Dimensions and finish of standard test specimens. The standard test specimens for verification of compositions for projectors shall be ceramic rings with a surface finish before electroding not to exceed 1.60 micrometer (63 μinches). The outside diameter wall and the inside diameter wall shall be perpendicular within .250 mm (.010 inch) to the electrode surfaces. The dimensions of the finished poled rings shall be as follows:

Outside diameter 63.50 $\pm$ 0.635 mm (2.5 $\pm$ 0.025 inches)
Length or height 12.70 $\pm$ 0.25 mm (0.5 $\pm$ 0.010 inch)
Wall thickness 6.35 $\pm$ 0.760 mm (0.25 $\pm$ 0.030 inch) except that the wall thickness of any individual specimen shall not vary more than 0.760 mm (0.030 inch) total.

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

5.2.1.1.1 Adherence. The electrode adherence shall meet the test specified in 5.2.4.1.8.

5.2.2 Markings. The rings shall be marked on the outer cylindrical surface with nonconducting ink to identify the manufacturer, the powder lot number, and the poling date. The electrode to which the positive side of the power supply is attached during poling shall be marked with a suitable designation, such as a dot or +, with a nonconducting ink on the outer cylindrical surface adjacent to that electrode face. The markings shall be as small as practicable, but legible.

5.2.3 Poling. The standard test rings shall be poled in the axial direction.

5.2.4 Requirements.

5.2.4.1 Examination and tests for standard test ring specimens.

5.2.4.1.1 Method. The measurements as specified in 5.1.4.1.2 through 5.1.4.1.7 shall be performed in accordance with the methods of IEEE 176.

5.2.4.1.2 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 III for the particular type of material required. The density shall be determined to an accuracy of 0.2 percent.

5.2.4.1.3 Small signal properties. The small signal values of the free relative dielectric constant, K^T_{33}, the dielectric loss factor, tan δ, the effective piezoelectric coupling factor, k^2_{eff}, and the frequency constant, N_1 of each test specimen shall be measured three times in the period between 10 and 100 days after poling. K^T_{33} and tan δ shall be measured at 1 kHz.

5.2.4.1.3.1 Time of measurements. The first set of measurements of K^T_{33}, tan δ, k^2_{eff}, and N_1 shall be made within 20 days after the poling, the second set approximately 45 days after poling, and the third set approximately 100 days after poling. The three sets of data shall be plotted against the logarithm of the time in days since poling and the values at 10 and 100 days shall be determined by extrapolation using a best fit to a straight line. The 10-day values and the aging rates (excluding the rate for tan δ) per time decade from 10 to 100 days shall fall within the limits shown in table III.

5.2.4.1.4 Quality factor, Q_m, and temperature characteristic of K^T_{33}. After the final set of small signal measurements of K^T_{33}, tan δ, k^2_{eff}, and N_1 have been completed, but not later than 110 days after poling, the mechanical quality factor, Q_m, and the temperature characteristic of K^T_{33} shall be measured in that order and the corresponding values shall fall within the limits shown in table III. The percentage change in K^T_{33} shall be determined during a heating cycle. The specimen shall be cooled at 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 electrodes 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.

5.2.4.1.5 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 at electric fields specified in table IV for the appropriate type of material and the measured values shall be less than or equal to the values shown in table IV. Modified types (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. 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. For reliable results on larger parts, this test shall be performed with leads soldered directly to the parts.

5.2.4.1.6 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 5.1.

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

5.2.4.1.8 Electrode adherence. 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 50 mm (nominal 2 inches) wide and 80 mm (3.15 inches) long with an adhesion greater than 50 oz/inch (13.9 N/25 mm) width, shall be pressed firmly across the diameter of the electrode. The tape shall remain in contact with the surface for at least 24 hours at a temperature between 20 and 25°C. One end of the tape shall then be lifted normal to the electroded surface forming a 90 degree angle. Continue to pull the tape until it is removed. The removal of any portion of the electroded surface with the tape shall be considered a failure to pass this test. More than two such failures out of ten test specimens is unacceptable. (This test applies only to the standard test specimens. The test required for first article and production ceramic elements shall be specified in the individual equipment or ceramic element specification.)

Preparing activity:
Navy - SH
(Project 5845-N071)

APPENDIX A

DATA REQUIREMENTS

10. DATA

10.1 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 DAR 7-104.9 (n)(2) are invoked and the DD Form 1423 is not used, 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 is cited in the following paragraphs.

Paragraph no.	Data requirements title	Applicable DID no.	Option
3.1.3 and appendix B, 50.8	Drawings, engineering and associated lists	DI-E-7031	Level 3 Design activity designation - Contractor Design activity drawing numbers - Contractor Delivery of hard copy - Contracting activity
4.1.1.2	Certificate of compliance	DI-E-2121	----
4.2.5	Inspection system program plan	DI-R-4803	----

(Data item decriptions 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.)

10.1.1 The data requirements of 10.1 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 identical item acquired to this standard. This does not apply to specific data which may be required for each contract, regardless of whether an identical item has been supplied previously (for example, test reports).

APPENDIX B

GUIDANCE IN SELECTION OF TYPE OF CERAMIC

10. GENERAL

10.1 Scope. This appendix furnishes additional background to be used for guidance and to assist in the selection of the types of ceramic to be used when piezoelectric ceramic is required in the individual equipment specification.

20. REFERENCED DOCUMENTS

20.1 Issue of documents. Not applicable.

30. DEFINITIONS

30.1 Definitions of physical flaws found in ceramic elements. The individual equipment specifications must specify the maximum size and number of each type that is acceptable in the ceramic element. In addition to any specific requirements, any flaw in the ceramic element large enough to degrade the performance for its intended use is unacceptable.

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

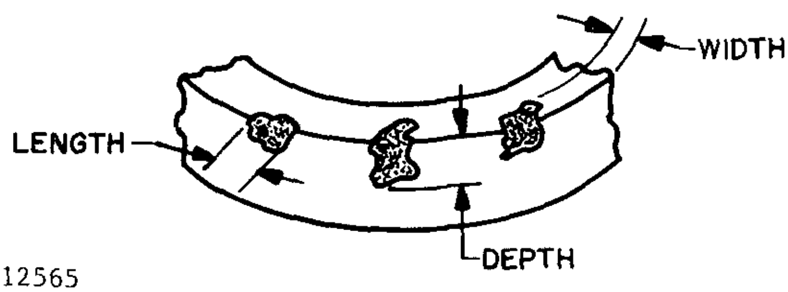

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FIGURE 2. Open chips.

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

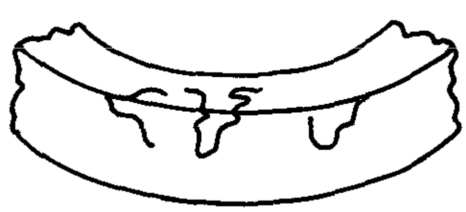

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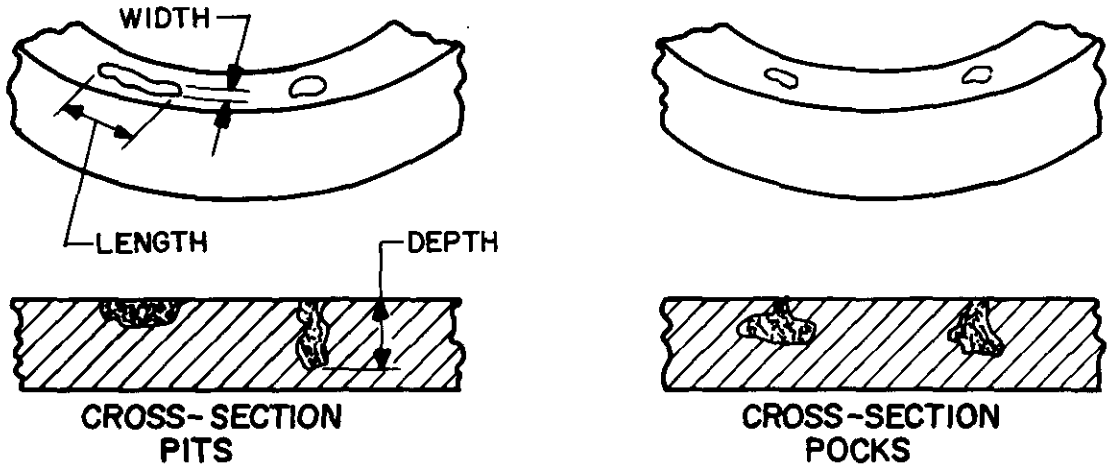
FIGURE 3. Closed chips.

30.1.3 Pits and pocks. A pit is an open cavity on any surface. A pock is a partially closed pit (see figure 4).



SH 12567

FIGURE 4. Pits and pocks.

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 can cause it to part along the line of fracture.

40. GENERAL REQUIREMENTS

40.1 Manufacturing restrictions. Because of variations in raw materials, the piezoelectric ceramic general properties tend to drift or change over a time period. The manufacturer is dependent upon suppliers of lead oxide, titanium dioxide, zirconium dioxide, and so forth, with respect to purity, particle size, particle shape and particle size distribution. All of these parameters introduce variables which affect the characteristics of the final ceramic.

40.1.1 Despite these obstacles to a completely uniform product, most 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.

40.1.2 The problem in meeting the specifications in production is essentially one of achieving the proper combination of dimensional requirements within the elastic, piezoelectric, and dielectric requirements and doing it economically.

40.2 Guidelines for specifications.

40.2.1 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 equipment specifications and tolerances established for each parameter.

40.2.2 When practicable, incorporate within the design a means of accommodating either changes in ceramic dimensions or electro-elastic properties.

40.2.3 Do not restrictively specify both dimensions and electro-elastic properties within too narrow limits.

40.2.4 If the design must be within narrow limits, determine which is the more economical, to accommodate adjustment in the electrical design, or to pay a higher price for closely controlled or selected ceramic elements.

40.2.5 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. Care must be exercised in selecting the dimensions of the ceramic element to minimize the excitation of multiple modes.

40.2.6 Prepare as complete specifications as possible to provide the manufacturer with realistic requirements and specify the most important physical and electro-mechanical properties.

40.2.7 This standard should be used as a guide in preparing the specification and to identify the type material to be specified. In hydrophone designs where uniformity of sensitivity is important, it may be necessary to establish limits on the piezoelectric constants g or d, for that particular application. In some cases, a method for measuring the sensitivity of the individual elements should be established, as for example, the use of a USRD type G19 bench calibrator or equivalent for measuring the sensitivity of capped cylinders.

40.2.8 On unusual design configurations or where close tolerances on either or both electrical and 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.

50. DETAILED REQUIREMENTS

50.1 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.

50.2 Electrodes. The electrode material may be silver, electroless nickel, copper, electro-plated nickel or gold. Fired silver is the most common type found in the industry while electroless nickel has been used to a lesser extent. The quality of an electrode is best defined by the three factors: adhesion, surface finish and conductivity.

50.3 Electrode adhesion test. One method for testing for electrode adhesion is detailed hereinafter. Since this is a destructive test, the quantity of test specimens in a given lot or order must be specified.

50.3.1 Equipment required.

(a) Soldering iron - 40 watts (approximately).
(b) Fluxes: noncorrosive rosin flux for fired silver; Superior #30 (or equivalent) for electroless nickel.
(c) Tinned test wires 0.64 mm (0.025 inch) diameter solid wire with 1.3 mm (0.05 inch) diameter upset heads. (Available commercially such as resistor leads).
(d) Solder (silver electrodes) 62 percent tin, 36 percent lead and 2 percent silver.
(e) Solder (electroless nickel electrodes) 60 percent tin, 40 percent lead.
(f) A lead alinement fixture.
(g) Tensile tester - 0 to 25 pounds (0-111 N) range.

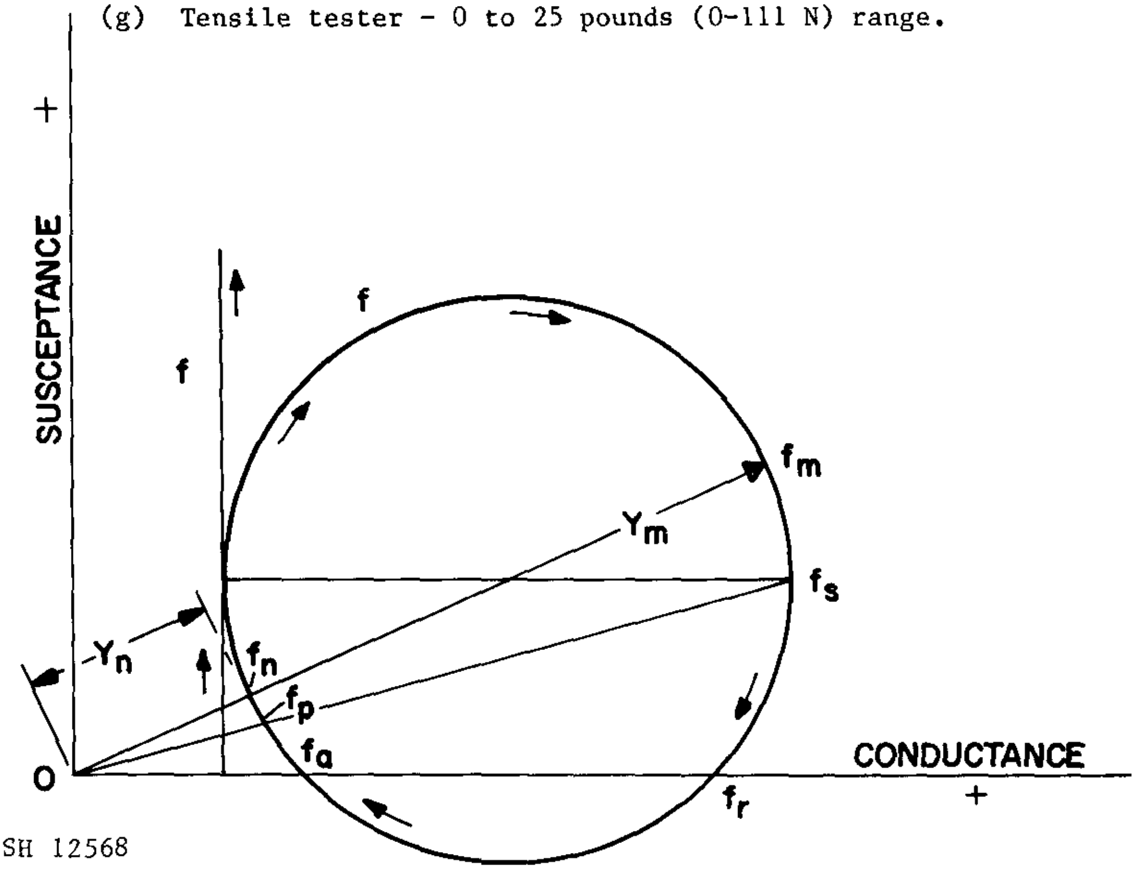


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FIGURE 5. Vector admittance diagram of a piezoelectric resonator.

50.4 Preliminary preparations.

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

50.5 Soldering procedure.

(a) Touch tinned tip of lead to surface of appropriate flux.
(b) Clip lead into alinement fixture with tinned end down.
(c) Position lead over the clean pretinned 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 approximately 2 to 3 mm (0.125 inch) above the tinned end.
(e) While applying firm downward finger 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. (Not greater than 3.0 mm (0.125 inch diameter).
(g) As soon as solder melts, withdraw the soldering iron but do not 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 alinement fixture clip and remove the fixture without touching the lead.
(i) It is not necessary to remove excess flux from the electrode surface.

50.6 Tensile testing.

(a) Set the tensile tester for the 0 to 25 pound (0 to 111 N) range and set the pointer to zero.
(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 mm/min (0.2 to 0.4 inch/min).
(d) Continue loading until the lead separates or an 8 pound (35 N) pull is indicated on the dial.
(e) Record the indicated value, relax and load, remove the lead from the fixture and repeat the test procedures for a total of six test leads (three for each major electroded surface unless otherwise specified). Not more than one pull under 8 pounds (35 N) is allowed.

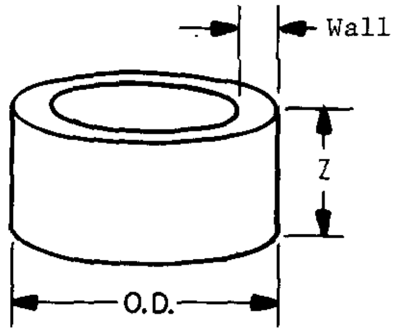
NOTE: Exceptions to adhesion test: The adhesion test outlined in 50.3 through 50.6 is not applicable to ceramic parts having a dimension between the electrodes of 1.27 mm (.050 inch) or less. In addition, the adhesion test is not applicable where any electroded dimension is smaller than 1.57 mm (.062 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, with an adhesion of 50 to 100 oz/inch (14 to 28 N/25 mm) width, can provide a suitable test (see 5.4.1.7).

50.7 Mechanical dimensions and tolerances. Typical variations in mechanical dimensions and tolerances are shown in table V for cylinders, tubes and rings; and table VI for discs and plates. These tables can be used as a guide in preparing specifications; however, the ceramic manufacturer should be consulted to determine that a specific tolerance can be maintained on production quantities.

50.8 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 pocks permitted. The drawing should be prepared in accordance with the data ordering document (see appendix A).

50.9 Suggested ordering data or specification guide. Table VII presents information which is typically required in specifying or describing a ceramic element. It is not necessary to specify every item listed. Only the items necessary to describe the element in sufficient detail to obtain the required performance for the intended purpose should be included. Over specifying the ceramic element will not only increase the cost but can invite diametrically opposite requirements.

TABLE V. Mechanical tolerance levels for cylinders-tubes-rings.



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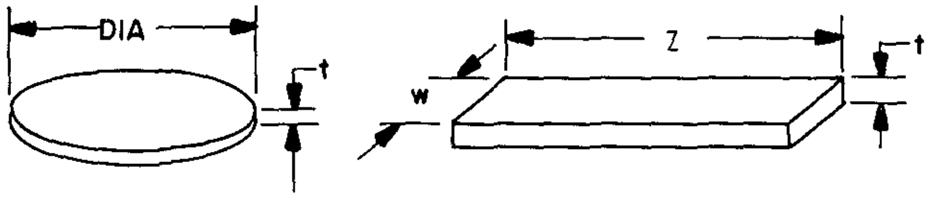
Cylinder-tube-ring (o.d.) Inch	Millimeter	Level A Fully machined(±) Inch	Millimeter	Level B Minimal machining(±) Inch	Millimeter	Level C as fired (±) Inch	Millimeter
0.250-0.500	6.35- 12.7	0.002	0.05	0.010	0.25	0.020	0.50
.500-1.000	12.7 - 25.4	.003	0.08	.015	0.38	.030	0.76
1.000-2.000	25.4 - 50.8	.003	0.08	.025	0.64	.050	1.27
2.000-3.000	50.8 - 76.2	.004	0.10	.030	0.76	.060	1.52
3.000-4.000	76.2 -101.6	.004	0.10	.050	1.27	.090	2.29
4.000-6.000	101.6 -152.4	.005	0.13	.060	1.52	.125	3.18
(Wall)							
0.020-0.031	0.51- 0.79	.002	0.05	0.005	0.13	0.005	0.13
.031- .063	0.79- 1.60	.002	0.05	.005	0.13	.010	0.25
.063- .100	1.60- 2.54	.003	0.08	.010	0.25	.015	0.38
.100- .125	2.54- 3.12	.003	0.08	.015	0.38	.020	0.51
.125- .250	3.17- 6.35	.004	0.10	.020	0.51	.030	0.76
.250- .350	6.35- 8.89	.004	0.10	.030	0.76	.040	1.02
.350- .500	8.89- 12.70	.005	0.13	.035	0.89	.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
.250-2.000	6.35- 50.8	.005	0.13	.010	0.25	.015	0.38
2.000-4.000	50.8 -101.6	.010	0.25	.015	0.38	.020	0.51
4.000-6.000	101.6 -152.4	.010	0.25	.015	0.38	.030	0.76
Squareness within:		0.5 degree per 1 inch length		1.5 degrees per 1 inch length		2.5 degrees per 1 inch length	

Parallelism and flatness of ends - See note next page.

NOTE: The tolerance for the parallelism and flatness of the ends of the tube is related to the diameter, wall thickness and length. Smaller sizes of diameter and length can be manufactured with tolerances of 0.03 mm (0.001 inch). The larger diameter and lengths in the order of 160 mm (6.30 inches) cannot be held to this tolerance and can be expected to run within 0.25 to 0.30 mm (0.010 to 0.012 inch). The manufacturer of the ceramic element should be consulted to determine the tolerance that can be guaranteed for a particular size ceramic element in production quantities.

TABLE VI. Mechanical tolerance levels for plates and discs.



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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	.005	±0.13	.015	0.38	.020	0.50
2.500-3.500	63.5 - 88.9	.005	±0.13	.020	0.50	.025	0.64
3.500-4.500	88.9 -114.3	.010	±0.25	.025	0.64	.040	1.02
4.500-6.000	114.3 -152.4	.010	±0.25	.030	0.76	.050	1.27
Disc and plate (thickness) (t)							
0.010-0.015	0.25- 0.38	0.001	±0.03	0.002	0.05	0.002	0.05
.015- .035	.38- .89	.001	±0.03	.002	0.05	.003	0.08
.035- .080	.89- 2.03	.002	±0.05	.003	0.08	.004	0.10
.080- .200	2.03- 5.08	.003	±0.08	.008	0.20	.010	0.25
.200- .500	5.08- 12.70	.004	±0.10	.010	0.25	.015	0.38
.500-1.0	12.70- 25.40	.005	±0.13	.020	0.50	.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 diameter for disc 2 inches or plates Z or W 2 inches)		0.001	0.03	0.003	0.08	Within thickness tolerance up to 1 inch diameter and up to 0.080 inch thick. Within 0.005 inch above 0.080 inch 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 inches) are required the manufacturer should be consulted on the tolerance that can be maintained on production quantities.

TABLE VII. Suggested ordering data and specification guide.

1. Application:

Projector ______________ Hydrophone ______________
Other ________ (describe) ______________________

____

2. Ceramic type: I_____; II_____; III_____; IV_____; Modified_____

Property:

Nominal value required:

K_{33}^{T} ____	tan δ ____	k_{eff}^{2} ____	k_p ____	N_1 ____	N_p ____	Q_m ____	Other ____

3. Geometric description:

Cylinder____; Disc____; Plate____; Bar____; Sphere____; Hemisphere____

Other____ (describe) ______________________________

____

____

4. Dimensional requirements:

		Tolerance level A	Tolerance level B	Tolerance level C	Tolerance level *AA
O.d.	________				
Length	________				
Wall	________				
I.d.	________				
Width	________				
Flatness	________				
Parallelism	________				
Perpendicularity (squareness)	________				

*As specified in equipment specifications See reference drawing no. ______________

5. Other special requirements ______________________________

____

____

TABLE VII. Suggested ordering data and specification guide. - Continued

6. Chips; pits and pocks:

	Open chips	Closed chips	Pits	Pocks
Maximum allowable size				
Maximum number per surface				

Reference drawing number ______________________________

7. Electrode material:

Silver __________; electroless nickel __________

Other __________ (specify) ______________________________

8. Placement of electrodes:

Major surfaces ______; Ends ______; O.d.-I.d. ______; Stripes ______

Other ______________________________

Borders ______________, Describe ______________________________

____

9. Electrode connection:

None ______; Wire size ______ (describe wire type and stranding) ______

____

Location of point of attachment ______________________________

Other special requirements ______________________________

10. Poling direction: Radial ☐; Longitudinal ☐; Tangential ☐; Other ☐

Describe ______________________________

11. Reference drawing number of ceramic element ______________________________

TABLE VII. Suggested ordering data and specification guide. - Continued

12. Electrical properties (10 days after poling) low field

Capacitance C^T ________ pF(± ____________ pF)

Dielectric loss factor (max value) tan δ ________ Not required unless different from value specified in tables II and III.

Maximum admittance magnitude 1/ Y_m ____________ siemens (S) (minimum value)

Frequency of maximum admittance 1/ f_m ____________ Hz (± ____________ Hz)

Minimum admittance magnitude 1/ Y_n ____________ siemens (S) (maximum value)

Frequency of minimum admittance 1/ f_n ____________ Hz (± ____________ Hz)

1/ These parameters or their equivalent shall be specified for the production ceramic element.

13. High field measurements required: Yes [ ]; No [ ]

Maximum change in K_{33}^T 0 to 50°C; as specified in table IV [ ]

Different value required; ____________ percent [ ]

Maximum dielectric loss factor; as specified in table IV [ ]

Different value required; tan δ ____________ [ ]

14. Sets of electrical measurements required on production ceramic elements:

One [ ]; Two [ ]; Time between measurements; ________ days.

15. Test data sheet required: Yes [ ]; No [ ]

Test data format to be approved by contracting activity [ ]

16. Estimated production quantities

Minimum ____________ Maximum ____________

17. Number (quantity) of first article ceramic elements ____________

18. Manufacturers test procedure approval required Yes; ______ No; ______

Approval required by ______________________________
(Activity - Title - Name)

Material: Type__________ of DOD-STD-1376

Capacitance ______pF ± ______pF (1 kHz)

Maximum admittance $|Y_m|$______________S
(min value)

Frequency f_m at $|Y_m|$__________Hz ± __________Hz

Minimum admittance $|Y_n|$______________S
(max value)

Frequency f_n at $|Y_n|$__________Hz ± __________Hz

Notes:

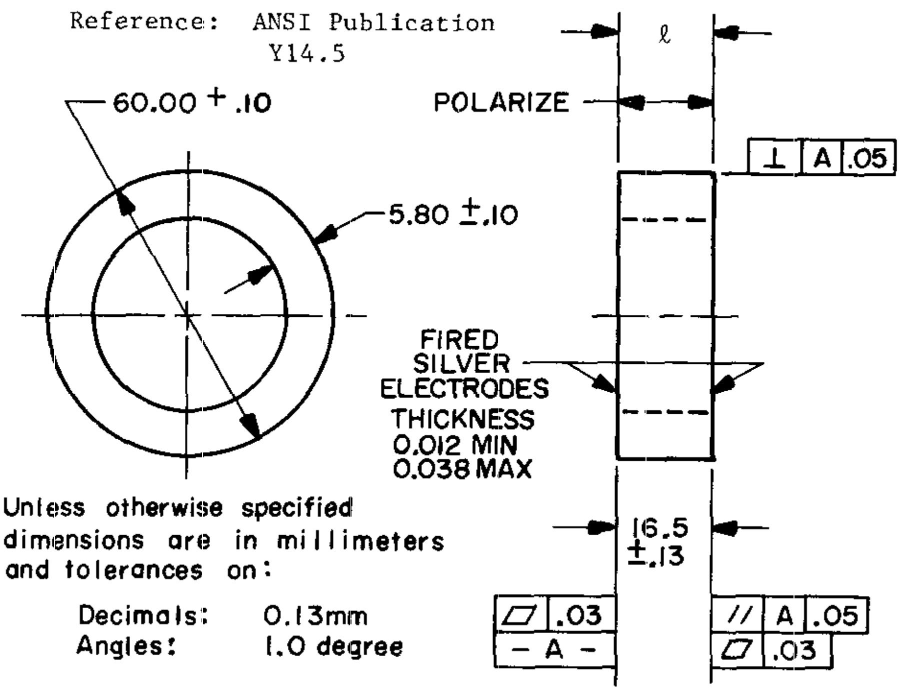
1. The number of chips or edge irregularities shall not exceed five total. The number of chips on any surface shall not exceed two.

2. Markings indicating the type material shall be color coded in nonconducting ink and shall be placed as close to the positive electrode as practical on the outside cylindrical surface.

3. Mark the poling date in nonconducting ink on the outside cylindrical surface.

4. The ends and outside cylindrical surface finish shall not exceed 1.02 micrometer (40 microinches) before electroding.

5. Electrodes: The plane surface shall be fully covered with fired-on silver electrodes (duPont 6010 or equivalent). The silver shall not extend onto the curved surfaces (inside or outside).



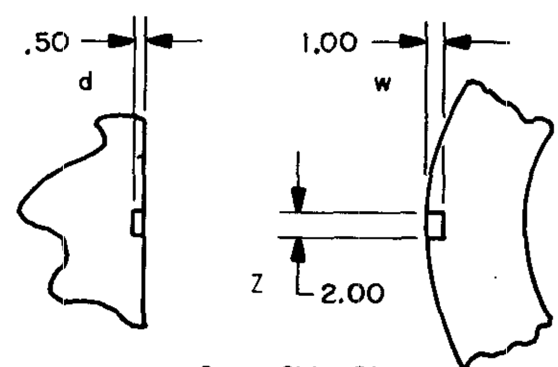


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FIGURE 6. Typical format for production ceramic elements - ring.

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STANDARDIZATION DOCUMENT IMPROVEMENT PROPOSAL

(See Instructions – Reverse Side)

1. DOCUMENT NUMBER
DOD-STD-1376A(SH)

2. DOCUMENT TITLE
PIEZOELECTRIC CERAMIC FOR SONAR TRANSDUCERS (HYDROPHONES AND PROJECTORS)

3a. NAME OF SUBMITTING ORGANIZATION

b. ADDRESS *(Street, City, State, ZIP Code)*

4. TYPE OF ORGANIZATION *(Mark one)*

- ☐ VENDOR
- ☐ USER
- ☐ MANUFACTURER
- ☐ OTHER *(Specify)*: ______

5. PROBLEM AREAS

a. Paragraph Number and Wording:

b. Recommended Wording:

c. Reason/Rationale for Recommendation:

6. REMARKS

7a. NAME OF SUBMITTER *(Last, First, MI)* – Optional

b. WORK TELEPHONE NUMBER *(Include Area Code)* – Optional

c. MAILING ADDRESS *(Street, City, State, ZIP Code)* – Optional

8. DATE OF SUBMISSION *(YYMMDD)*

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