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NBS Technical Note 1233

Requirements for the Calibration of Mechanical Shock Transducers

D. C. Robinson

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1. Overview

1.1 Introduction

The Engineering Working Group of the Tri-Service's Calibration Coordination Group (CCG) has prepared a 5-year plan designed to provide solutions to DOD's current calibration problems and to address technologies which require metrology and calibration support essential to the operation of modern, sophisticated military hardware. This Metrology and Calibration (METCAL) Research, Development and Engineering (RD&E) Plan was first prepared in 1983 and has subsequently been revised and updated [1].

As noted in the 1985 METCAL RD&E Plan, the use of obsolete, inadequate, or nonexistent calibration standards during weapons system development and acquisition makes both the DOD and its contractors unable to validate system performance legally during testing, evaluation and production acceptance [1]. DOD METCAL organizations are unable to maintain confidence in their own test results when it is impossible to compare their critical measurements to higher accuracy national standards. To correct current weaknesses and to meet the DOD calibration requirements of the immediate future, in areas of physical and mechanical metrology such as mechanical shock, new calibration standards must be developed and existing standards must be improved.

In order to establish a valid basis for the improvement of existing calibration standards for mechanical shock, a telephone survey was made to define current needs for the calibration of accelerometers in shock measurement applications. The results of this survey of various government agencies and government contractors who are actively engaged in the measurement of shock motions of 100 g or higher is described in this report (the acceleration amplitude is described as a dimensionless multiple of the gravitational constant g). Among the organizations contacted for this survey were: (1) major test laboratories of the three Services, (2) laboratories within DOE, NASA, and government contractors engaged in the measurement of high amplitude shock motion, and (3) several manufacturers of accelerometers and associated dynamic instrumentation.

As part of the effort to establish current needs for the calibration of accelerometers, a study was made of the accuracy requirements in various engineering applications for the measurement of shock motions up to 200,000 g, and an evaluation was made of the accuracy required to calibrate such transducers for various ranges of acceleration. The principal results of these investigations are given in the following sections of this report, with some detailed information about the survey being provided in the appendices.

1.2 Questionnaire for Shock Accelerometer Users

The objective in formulating the questionnaire for shock accelerometer users was to identify problem areas in shock measurements and inadequacies in calibration standards as a basis to begin developing those improved shock calibration services felt to be most urgent by the survey respondents. A telephone survey of four transducer manufacturers and approximately 45 users of shock accelerometers was made to determine the accuracy requirements in various engineering applications and to evaluate the accuracy required to calibrate accelerometers for several ranges of acceleration up to 200,000 g. The data from this survey are biased toward high-level-shock users, where the most urgent calibration needs have become evident. The user respondents were selected to represent government agencies, government contractors, and independent test laboratories who were likely to be performing a wide variety of shock tests.*

The content of the questionnaire form is shown in the following section. In addition to the prepared questions, the respondents were encouraged to provide relevant information useful in assessing the accuracy actually being achieved in the measurement and calibration of shock accelerometers. User identification and general survey information is given in Appendix A. The subject of nonlinear effects in acceleration measurements was discussed with several users and transducer manufacturers to determine where assumptions are made concerning accelerometer linearity in the calibration process. This information is summarized in Appendix B of this report.

1.2 SHOCK USER QUESTIONNAIRE FORM

1. User ID
2. User Type ___Army ___Navy ___AF ___DOE ___NASA
   ___Industrial User of Shock Measurements
   ___Transducer Manufacturer
3. Organization
4. Address
5. City
6. State
7. Zip Code
8. Name of Contact
9. Telephone Number
10. Reason for/description of shock measurement application
11. Lowest amplitude of interest (g)
12. Highest amplitude of interest (g)
13. Lowest frequency of interest (Hz)
14. Highest frequency of interest (Hz)
15. Uncertainty needed (%)
16. Uncertainty being achieved (%)
17. How calibration is now achieved
18. Comments
    Suggestions for other contacts

2. Results of Shock User Survey

The principal results of the telephone survey are given in this section. User identification information, represented by the first nine items in the questionnaire form, is given in Appendix A. The shock measurement application

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*Certain commercial companies and their products are identified in this report to adequately specify the results of the survey. Such identification does not imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the products mentioned are necessarily the best available for the purpose or that NBS accepts the performance and accuracy claims made by these firms.

and maximum shock amplitudes and maximum frequencies of interest, items 10, 12 and 14, respectively, are given in Table 1. The lowest amplitudes of interest, item 11, were usually 10 g or less and the lowest frequency of interest, item 13, was generally down to DC; these responses are not tabulated. The response to items 12 and 14, the maximum acceleration amplitudes and frequencies of interest, respectively, are also summarized in Figure 1.

The response to items 15 through 17 are given in Table 1 and in the following text. The respondents did not always provide clear quantitative information regarding the uncertainties and methods of calibration, and they frequently provided information on general measurement problems instead. This latter information is briefly summarized in Appendix A.

Table 1 Tabulation of User Survey Responses by Accuracy Requirement

USER**	APPLICATIONS	MAXIMUM AMPLITUDES (kilo-g)	MAXIMUM FREQUENCY (kHz)	CALIBR. METHOD***	CLAIMED ACCURACY (%)	ACHIEVED ACCURACY (%)
GEN.DYN.	MIL.SPEC.	1.5	10	V.	5	5
H.D.L.	MIL.SPEC.	2	---*	V.	5	---*
HUGHES	MIL.SPEC.	2.5	---	D.B.	5	---
HUGHES	PYRO	2.5	---	D.B.	5	---
HUGHES	BALLISTIC	5	---	D.B.	5	---
N.R.L.	UNDERWATER	3	---	M.	5	---
PATUXENT	MIL.SPEC.	1	---	S.T.	5	---
U.E.R.D.	UNDERWATER	2	---	D.T.	5	---
WSTGHSE	MIL.SPEC.	1	---	V.	5	---
WH.SANDS	PYRO,M.SPC.	20	---	D.T.	5	---
FT.MONMTH	MIL.SPEC.	0.5	---	V.	(5-10)	5
KIRTLAND	BLAST	50	100	D.B.	(5-10)	(5-10)
BENDIX,NJ	MIL.SPEC.	1.2	---	V.	10	---
BENDIX.NJ	PYRO	2	---	V.	10	---
B.R.L.	BALLISTIC	5	5	V.	10	10
CAI OPT.	CUST.SPEC.	0.25	---	M.	10	---
CAI OPT.	MIL.SPEC.	0.4	---	M.	10	---
CAI OPT.	PYRO	100(F)	---	M.	10	---
D.T.BROWN	MIL.SPEC.	2.5	---	M.	10	---
D.T.BROWN	PYRO	30(F)	---	M.	10	---
H.D.L.	BALLISTIC	100(F)	---	D.B.	10	5
IND.HEAD	MIL.SPEC.	0.3	10	V.	5	5
LOCKHEED	PYRO	30	10	D.T.,V.	10	10
LOS ALMOS	WTR.IMPACT	50	70	D.B.	10	5
LTV DAL.	LRU	5(F)	---	V.	10	---
LTV DAL.	SUBSYST.	10(F)	---	V.	10	---
MRSHL SFC	PYRO	100	10	D.B.	10	(10-20)
MRTN MAR.	PYRO	10	10	D.T.	10	(5-10)
MCDAC CAL.	PYRO	100	---	D.B.,V.	10	---
MCDAC HNT.	PYRO	70(F)	80	D.B.	10	---
MOTOROLA	PYRO	30	---	M.	10	---
MOTOROLA	BALLISTIC	100	---	M.	10	---
NOSC S.D.	MIL.SPEC.	0.1	---	V.	10	---
NOSC S.D.	UNDERWATER	3	---	V.	10	---
NOSC S.D.	MIL 901	5	---	V.	10	---
NTS MFGS.	VARIETY	20	---	M.	10	---
PICATINNY	MIL.SPEC.	20	---	D.B.	10	10
ROCKTDYNE	BASTR.CMP.	20(F)	---	D.B.	10	---
SANDIA	VARIOUS	30(F)	30	D.B.	10	(6-8)
S.W.R.I.	BALLISTIC	30	50	D.T.	(5-15)	(5-20)
TRW,RDNDO	PYRO	25(F)	---	D.B.	10	---
WPAFB	MIL.SPEC.	1	---	V.	10	---
HOLLOMAN	IMPACT	100	10	D.B.	(10-15)	(15-20)
N.S.W.C.	BALLISTIC	50	20	S.M.	10	(15-20)
CHINA LK.	PYRO	40	40	D.B.	20	(20-30)
S-CUBED	BLAST	250	350	H.B.	10	(20-30)
ENG.WTRWY.	BLAST	1000	100	H.B.	20	(20-30)
ABERDEEN	BALLISTIC	1000	---	H.B.	50	---

*--- Indicates that no information was provided by the user.

** The full names of the shock accelerometer users are given in Appendix A.

*** V. - Vibration exciter, D.B. - Drop ball, M. - Manufacturer, S.T. - Shock tube, D.T. - Drop test, S.M. - Shock machine, H.B. - Hopkinson bar

(F) - Anticipated future maximum shock amplitudes for user are shown in Figure 2.

For low level shock measurements up to 10,000 g, users stated accuracy requirements of ± 5 to 10 percent. Shock accelerometers for MIL-STD-810D must meet the following specifications [2]: (1) transverse sensitivity, 5 percent maximum, (2) amplitude linearity, ± 10 percent over the range from 5 percent to 100 percent of the peak acceleration amplitude, and (3) frequency response, ± 10 percent from 5 to 2000 Hz, or to the highest frequency specified for the pyrotechnic shock spectrum. Few other military or civilian specifications mention accelerometer accuracy. Major manufacturers <u>claim</u> maximum probable errors of 1 to 5 percent. All the manufacturers surveyed <u>claim</u> NBS traceable capability up to a range of 10,000 g, several different calibration methods being employed. The respondents were uniformly satisfied with their perception that uncertainties less than 5 percent are achievable in this range.

Users expressed a desire for uncertainties of ± 10 percent in the range between 10.000 g and 100,000 g. Because manufacturers certify such accuracies of accelerometers rated in this range, most users believe they are getting such accuracies. A few of the users, however, are concerned about traceability of the calibrations in this range. Most shock tests and measurements in this range are specified by response spectra tolerances of ± 3 or ± 6 dB. Accelerometer uncertainties of ± 10 percent are generally judged to be acceptable for these measurements. Endevco offers a commercially available calibration service between 10,000 g and 100,000 g, with an estimated uncertainty less than 6 percent. Several government facilities also have similar capabilities, and <u>claim</u> an uncertainty of 6 percent. The accelerometer sensitivity information provided by the manufacturers in this range is extrapolated from lower level measurements.

3. Future Needs

Requirements for high shock measurements are increasing due to such factors as increasing use of electronics in projectiles, use of pyrotechnic devices in satellite and missile designs, and increasingly severe survivability requirements for military equipment and vehicles. Many of the tests performed at high levels are to assure compliance to contractual requirements for shock survivability. Nine of the respondents provided data concerning their anticipated future shock acceleration levels. These users are identified by the symbol (F) in Table 1. A plot of the present shock levels for all of the respondents is shown in Figure 2. A comparison of the present versus future shock levels for the accelerometer users who provided such data is given in Figure 3. These respondents also foresee an increase in the number of shock tests required, but this information was not quantified.

4. Discussion and Conclusions

The questionnaire for shock accelerometer users was designed to determine the accuracies needed and being achieved in both shock measurements and calibration of the accelerometers. The principal survey results are summarized in the following sections. Measurement uncertainty requirements at low shock levels (less than 10,000 g), if specified, are generally ± 10 or 15 percent. Measurement accuracies at higher levels are usually specified in terms of tolerances on shock response spectra. A few contractual requirements specify uncertainties of ± 10 percent.

Users stated accelerometer uncertainty requirements of ± 5 percent for low shock levels. Military specifications do not specify accelerometer uncertainties, although MIL-STD-810D specifies ± 10 percent [2]. At shock levels between 10,000 g and 100,000 g, uncertainties claimed by manufacturers of ± 10 percent are acceptable to the users surveyed. Very few users are making shock measurements above 100,000 g (the number of measurements per month for various acceleration levels reported by the respondents is shown in Figure 4, with the uncertainties also being noted). Those users are most concerned about survival of their instruments. However, they are concerned about the lack of unquestionable traceability at shock levels above 10,000 g.

For shock levels below 10,000 g, present specifications and calibration methods seem to be adequate. Major transducer manufacturers claim maximum probable errors of from 1 to 5 percent. Each of the 4 manufacturers surveyed claim NBS traceable capability in this range, several different calibration methods being used.

It should be noted that NBS does not presently offer a shock calibration service which is "traceable" either to sinewave calibrations above 10 g nor to any absolute shock measurements. The existing NBS shock facility provides a comparison calibration of accelerometers by subjecting them to half-sinewave pulses with peak amplitudes of 50 to 5000 g and pulse widths from 0.2 to 40 milliseconds. (There have been no requests from transducer manufacturers for this service.) The standard accelerometer used for this service has been calibrated at lower amplitudes, but its linearity has been checked only over a range of acceleration amplitudes up to 5000 g, using other accelerometers in their linear range.

In conclusion, the available services for -- and the current state of -- shock accelerometer calibrations will be briefly summarized. Most measurements and accelerometers are employed at shock amplitudes less than 10,000 g. Shock accelerometers are commonly calibrated in this range by a drop ball or by a gravimetric technique [3]; these low-level calibrations are directly traceable to NBS calibrated instruments. Endevco has sold approximately 100 drop ball shock calibration systems for shock levels below 10,000 g. Many independent calibration laboratories use the drop ball method. Sandia Laboratories and others have modified the drop ball calibration for higher acceleration levels.

In order to overcome the limitations in the short fixture used in many comparison techniques when the shock pulse-wavelength approaches the fixture/accelerometer dimensions, calibrations between 10,000 g and 100,000 g are limited to the use of some variation of a Hopkinson bar. The latter fixture is a long and slender elastic cylindrical bar which is longer than the wavelength of the shock pulse such that the entire pulse becomes embodied as a compression-wave which travels toward the test accelerometer mounted on the end. Very few calibration facilities maintain this capability, among them being Sandia Laboratories, Aberdeen Proving Ground, and S-Cubed (Systems, Science and Software). Above 15,000 g, Endevco uses a specially modified Hopkinson bar with the test accelerometer mounted on one end and struck by a projectile on the other end [4,5]. The bar is calibrated with a transfer standard which has been calibrated on the drop ball calibrator. Endevco estimates an uncertainty of 6.5 percent for this "test", which is not used on standard accelerometers and is available as an optional extra cost service. No other manufacturer offers calibration service above 15,000 g, and Endevco does not offer such service above 100,000 g.

There is no commercially available calibration service for shock levels above 100,000 g. The few users who are making shock measurements in this range are mostly concerned about survival of their instruments. The respondents who have current needs and others who foresee the need in the near future for shock measurements greater than 100,000 g would like to have a traceable, certifiable accuracy specification for shock levels in this range. In this regard, it should be noted that many of the respondents are performing tests which are contractually required and intended to resolve contractual compliance questions. Above 10,000 g to 100,000 g, "traceability" requires extrapolation from lower level calibrations. The extrapolations, in turn, require assumptions of the nature of linearity and frequency response of the standard accelerometers used. Several respondents expressed concern for the effects of transverse motion at the test frequencies in addition to the lack of assurances of linearity.

Some of the questions raised by this survey concerning the current state of shock transducer calibrations are: (1) Are the accelerometers used at ranges extending to over 100,000 g really linear between their usage level and their calibration level of less than 10,000 g? , and (2) Would the assumed accuracy stand up in court, if necessary?

5. Recommendations

Based on the results of this survey, the following recommendations are made for improving the state of calibration standards for mechanical shock accelerometers:

1. Conduct an NBS intercomparison of a variety of commercially available shock accelerometers in order to compare their sensitivities under standard sinewave calibration and shock calibration methods. The purpose of this is to determine the amplitude linearity of the selected accelerometers over as large an acceleration range as possible with existing calibration facilities.

2. Conduct a technical feasibility study to determine the technical approach and estimated program cost to develop NBS comparison shock calibration capability for shock amplitudes up to 30,000 g.

3. Conduct a technical feasibility study to determine the optimum technical approach and estimated cost for a future program to develop an absolute shock calibration capability for shock amplitudes up to 10,000 g.

4. Conduct a technical feasibility study to determine the optimum technical approach and estimated program cost to develop NBS shock calibration capability (absolute and comparison) for shock amplitudes up to 100,000 g.

6. Acknowledgments

The assistance of D. R. Flynn, M. R. Serbyn and B. F. Payne in developing the shock user questionnaire and in conducting the survey of shock accelerometer users is gratefully acknowledged. Useful information was obtained from Jon S. Wilson concerning the current state of shock accelerometer calibrations.

7. References

1. Tri-Service Metrology Research, Development, and Engineering Plan, Vol.1, Program Overview, CCG Engineering Working Group, Sept. 30, 1985.

2. MIL-STD-810D, Environmental Test Methods and Engineering Guidelines, Department of Defense, 1983.

3. Kobayashi, A.S., (Ed.), "Handbook on Experimental Mechanics" (Prentice Hall, 1987).

4. Sill, R.D., "Shock Calibration of Accelerometer at Amplitudes to 100,000 g using Compression Waves", Endevco Technical Paper 283, Endevco, Rancho Viejo Road, San Juan Capistrano, California, 1984.

5. Sill, R.D., "Testing Techniques Involved With the Development of High Acceleration Sensors", Endevco Technical Paper 284, Endevco, Rancho Viejo Road, San Juan Capistrano, California, 1985.

6. Wilson, J.S., " Accelerometers for Pyroshock Measurements", Proceeedings of the IES Pyrotechnic Shock Tutorial Session, May, 1985.

7. Powers, D.R., "Pyro Shock Test Simulation Methods", Proceedings of IES Pyrotechnic Shock Tutorial Session, May, 1985.

8. van Randeraat, J. and Setterington, R.E., (Eds.), "Piezoelectric Ceramics", (Mullard Limited, 1974).

9. Personal Communication with Jon S. Wilson, 1986.

10. Bouche, R.R., "Calibration of Shock and Vibration Measuring Transducers", Shock and Vibration Monograph Series SVM-11, The Shock and Vibration Information Center, Naval Research Laboratory, Washington, DC 1979.

Appendix A. General Shock Survey Information

Four manufacturers of accelerometers whose transducers are frequently employed by shock measurement users were surveyed: Dytran, Endevco, Kistler, and PCB. All four manufacture, calibrate, and recalibrate accelerometers with ratings up to 100,000 g. Endevco is the only manufacturer among these which makes both piezoelectric and piezoresistive accelerometers, one of the latter being rated higher than 100,000 g. Manufacturers' data sheets seldom state calibration uncertainty. Accuracies of calibration are stated in supplementary catalog information, or in listings of available calibration services. All four manufacturers perform vibration calibrations that are directly traceable to NBS; however, the traceability of their shock calibrations is more circuitous.

Forty five users of accelerometers for shock measurements were surveyed to determine usage, problems, and needs relative to shock calibrations. Among the government respondents there were nine Army, ten Navy, four Air Force, one NASA and three DOE laboratories. There were eighteen respondents from industrial contractors. There were several additional laboratories who were surveyed but did not provide enough useful information to be included in the tabulated results. Table A.1 gives a listing of all the various organizations who were contacted to determine the the current needs for shock measurements and shock accelerometer calibration requirements.

There were seven measurement problem areas identified from the telephone survey of shock accelerometer users. The three dominant problem areas identified among those laboratories engaged in measuring the largest shock motions were: (1) transducer survivability, (2) zero shift, and (3) insufficiently high resonance frequency of the accelerometer. These problem areas and their interactions have been discussed in a recent paper by Wilson [6].

The next two most frequently mentioned areas of concern were: (4) the accelerometer transverse sensitivity and (5) base or case strain sensitivity. Powers [7] has suggested that for some shock environments, an accelerometer may be subjected to simultaneous motion in and around all three orthogonal axes of the transducer. One of the survey respondents noted the Hopkinson bar was not an appropriate means for the calibration of accelerometers which are subjected to oblique shock motions of large amplitude.

The two problem areas least noted by most of the shock accelerometer users were: (6) cable noise and (7) temperature effects. Only one respondent suggested that he would find it useful to calibrate his accelerometers at the temperature extremes required by MIL STD 901C.

Ballistic and pyroshock tests are the applications with the highest acceleration level requirements. Several of the survey respondents who were most concerned with the fragility of accelerometers in pyroshock and similar measurements had dissected accelerometers which had failed in service, but these investigations were not conclusive in finding a dominant failure mechanism.

Table A.1 Tabulation of Shock Accelerometer Users Surveyed

I. Army Laboratories

1. Aberdeen Proving Ground (ABERDEEN)
2. Ballistic Research Laboratory (B.R.L.)
3. Engineer Waterways Experiment Station (ENG.WTRWY.)
4. Army Electronic R&D Command Fort Monmouth (FT.MONMTH.)
5. Harry Diamond Laboratories (H.D.L.)
6. Army Armament R&D Command- Picatinny Arsenal (PICATINNY)
7. White Sands Missile Range (WH.SANDS)
8. Army Tank Command
9. Yuma Proving Ground

II. Navy Laboratories

1. Naval Weapons Center- China Lake (CHINA LK.)
2. Naval Ocean Systems Command (NOSC S.D.)
3. Naval Research Laboratory (N.R.L.)
4. Naval Surface Weapons Center- White Oak (N.S.W.C.)
5. Naval Ordnance Station- Indian Head (IND.HEAD)
6. Naval Air Test Center- Patuxent (PATUXENT)
7. Underwater Explosions Research Development (U.E.R.D.)
8. Navy Primary Standards Laboratory
9. Naval Surface Weapons Center- Dahlgren
10. Naval Underwater Systems Center

III. Air Force Laboratories

1. Holloman AFB (HOLLOMAN)
2. Kirtland AFB (KIRTLAND)
3. Wright Patterson AFB (WPAFB)
4. Eglin AFB

IV. DOE Laboratories

1. Los Alamos (LOS ALMOS)
2. Sandia Laboratories (SANDIA)
3. Lawrence Livermore Laboratory

V. NASA Laboratory

1. Marshall Space Flight Center (MRSHL SFC)

VI. Industrial Contractors

1. Bendix, New Jersey (BENDIX,NJ)
2. CAI Optical (CAI OPT.)
3. Dayton T. Brown (D.T.BROWN)
4. Epoch Engineering, Inc.
5. General Dynamics (GEN.DYN.)

6. Hughes (HUGHES)
7. Lockheed (LOCKHEED)
8. LTV Dallas (LTV DAL.)
9. Martin Marietta (MRTN MAR.)
10. McDonnell Douglas, California (MCDAC CAL.)
11. McDonnell Douglas, Huntsville (MCDAC HNT.)
12. NKF Engineering Associates
13. NTS Massachusetts (NTS MASS.)
14. Rocketdyne (ROCKTDYNE)
15. Rosemount
16. Systems, Science & Software (S-CUBED)
17. TRW, Redondo (TRW,RDNDO)
18. Westinghouse (WSTGHSE)

Appendix B Nonlinear Effects in Accelerometer Designs and Materials

Nonlinearity is the change in sensitivity over the amplitude range. Accelerometer design and sensing material affect nonlinearity. Ceramic "crystals" inherently exhibit greater nonlinearity than quartz or other natural crystals. This is thought to be caused by partial depolarization of the artificially polarized materials as internal stress increases [8]. However, ceramics also provide greater charge sensitivity, so that nonlinearity of the crystal material within the usable range is often insignificant.

In general, the sensitivities of piezoelectric accelerometers increase linearly with acceleration. Nonlinearity of four or five percent is usually accepted for shock measurements. Nonlinearity specifications are usually based on worst-case production variations of a particular design, and acceleration ranges are sometimes established based on an acceptable nonlinearity for particular applications.

Undamped piezoresistive accelerometers generally exhibit very good linearity up to their fracture point. Damped piezoresistive designs may exhibit complex nonlinearity relationships caused by variations in damping. Wilson has noted that both piezoelectric and piezoresistive accelerometer designs may have nonlinearities caused by poor design or assembly practices. Adhesive characteristics, insufficiently torqued threaded fasteners, and defective crystal materials are some of the possible causes [9]. Nonlinearity may vary from unit to unit but it is not measured on a routine basis.

The principal issue raised regarding the above noted limitations in accelerometer materials and designs is whether accelerometers used at levels one or several orders of magnitude greater than their calibration level are really linear. Extrapolations require assumptions of the nature of linearity which may be unverified. One of the principal reasons for extending the range of existing standards for shock calibration to meet current measurement needs would be to verify the linearity of accelerometers over a larger range of shock amplitudes [10].

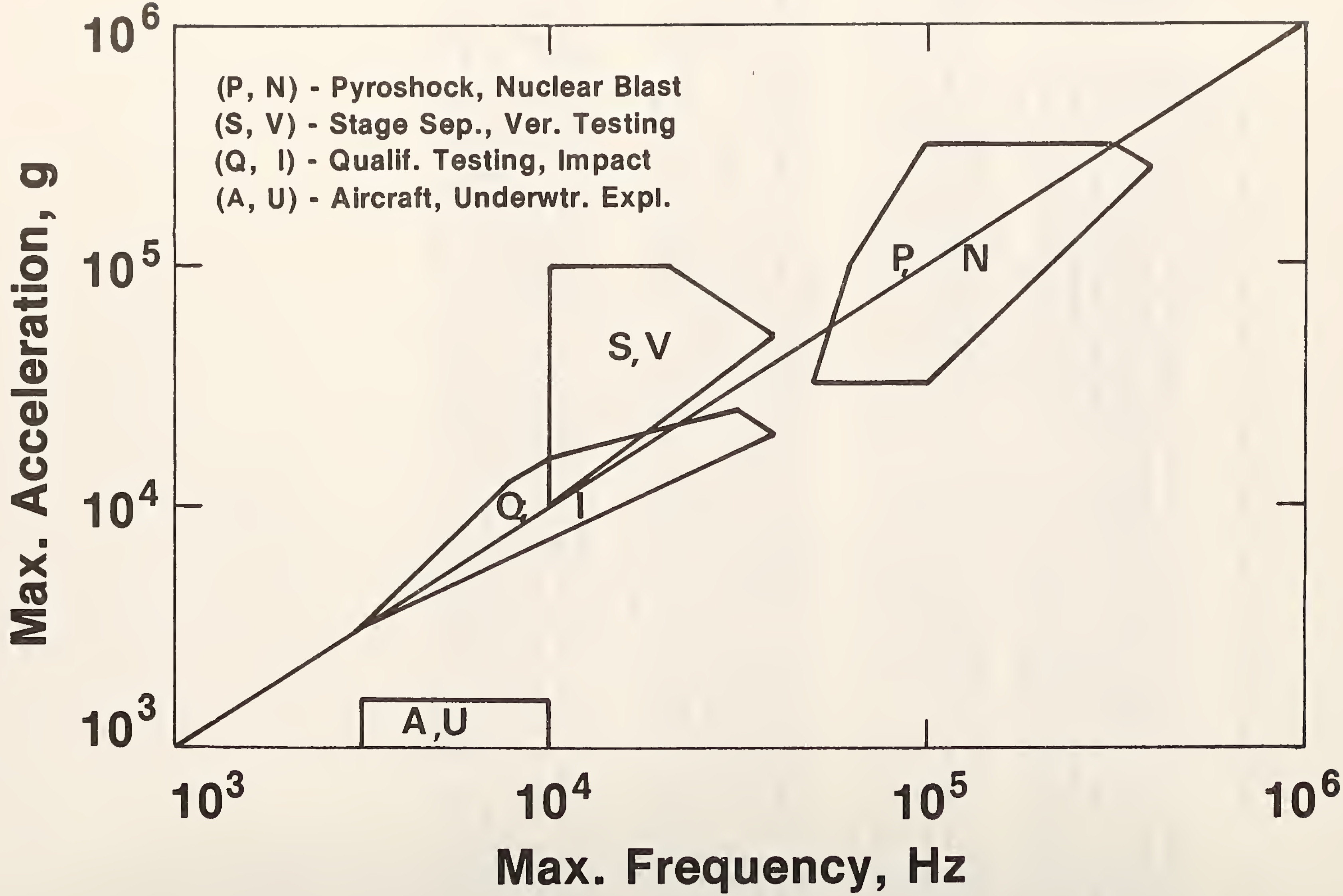

Figure 1 - Max. Frequency vs. Max. Acceleration in Shock Measurement Applications

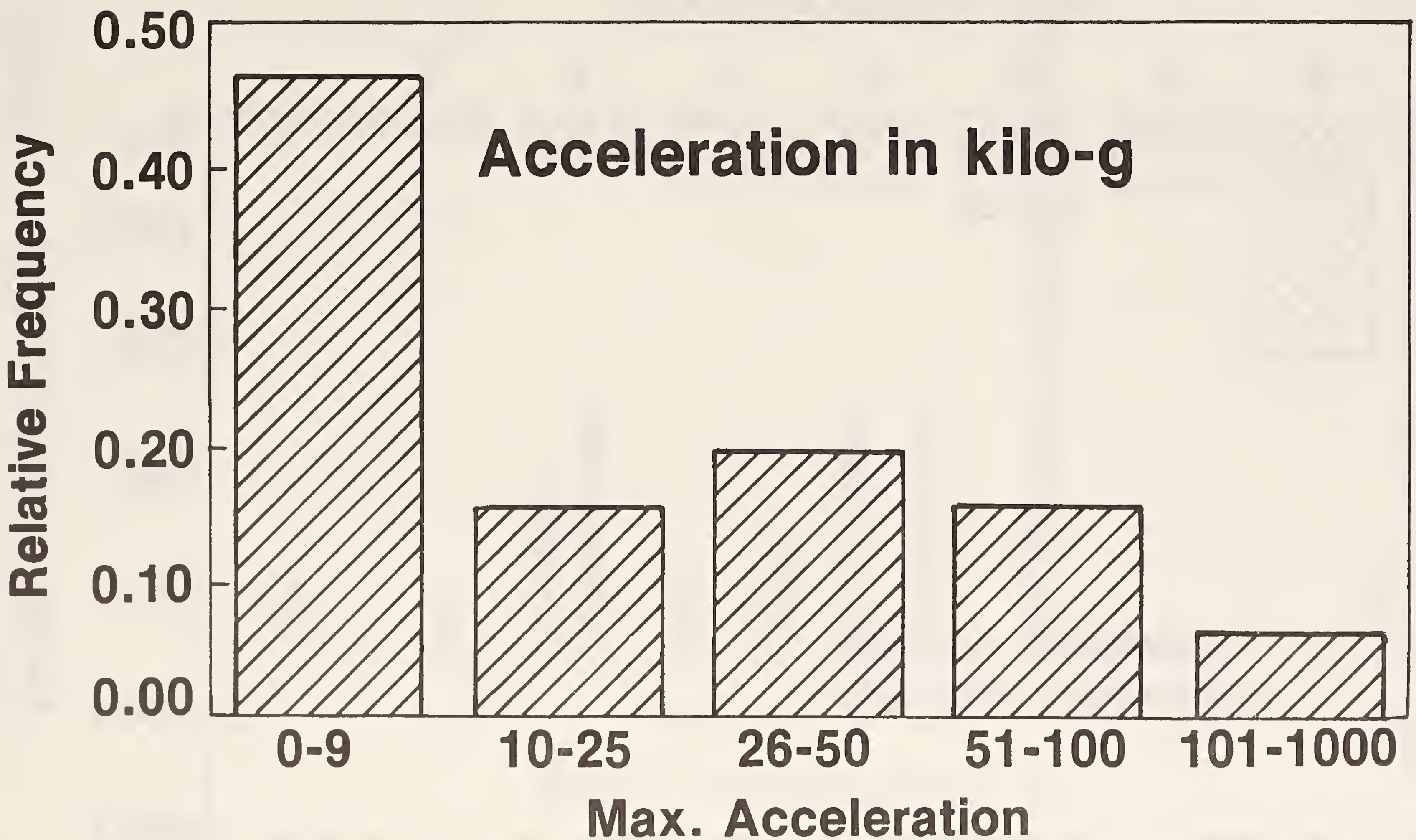

Figure. 2 Present Shock Levels for Accelerometer Users

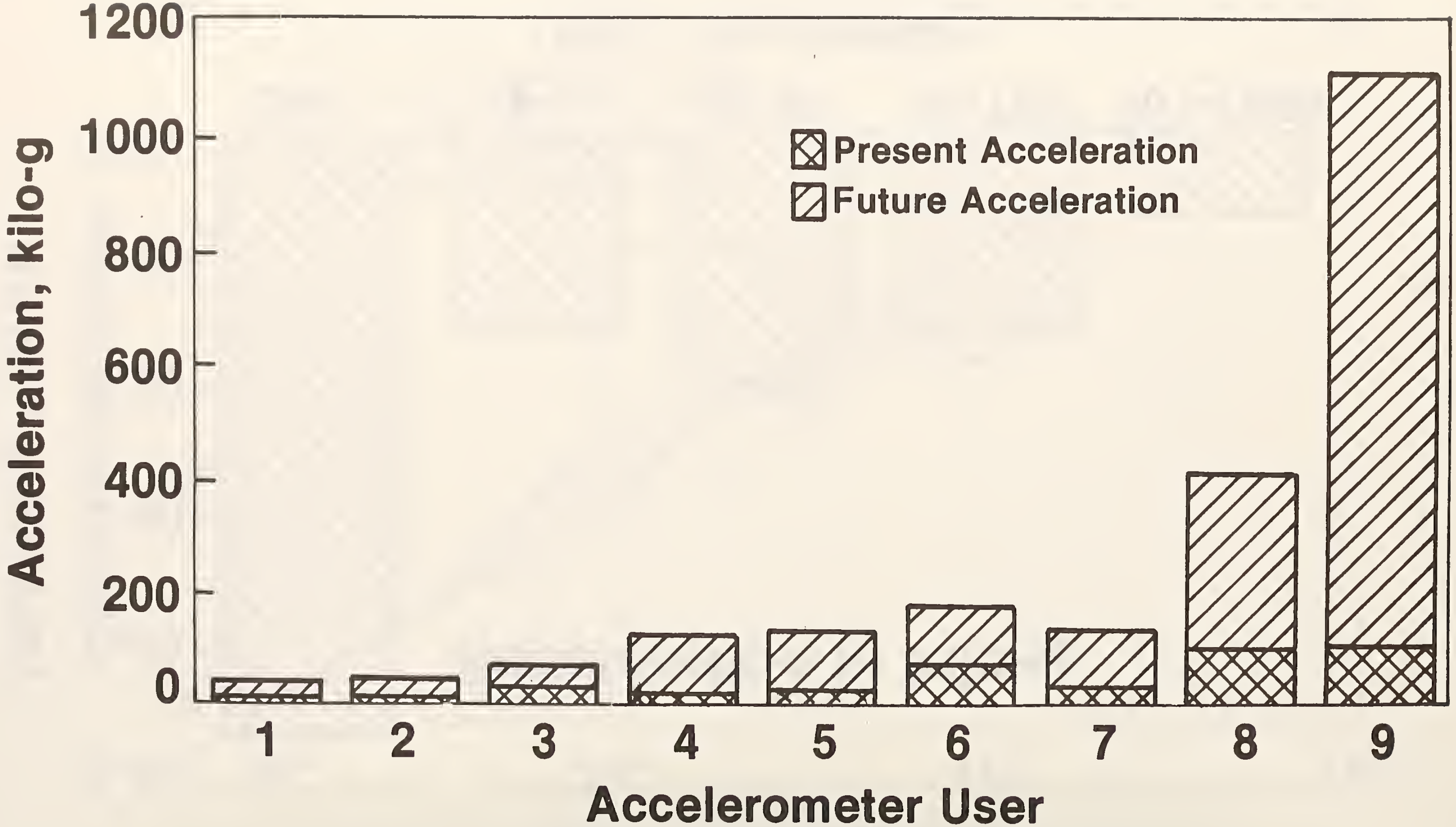

Fig. 3 Present and Future Maximum Shock Acceleration for Various Users

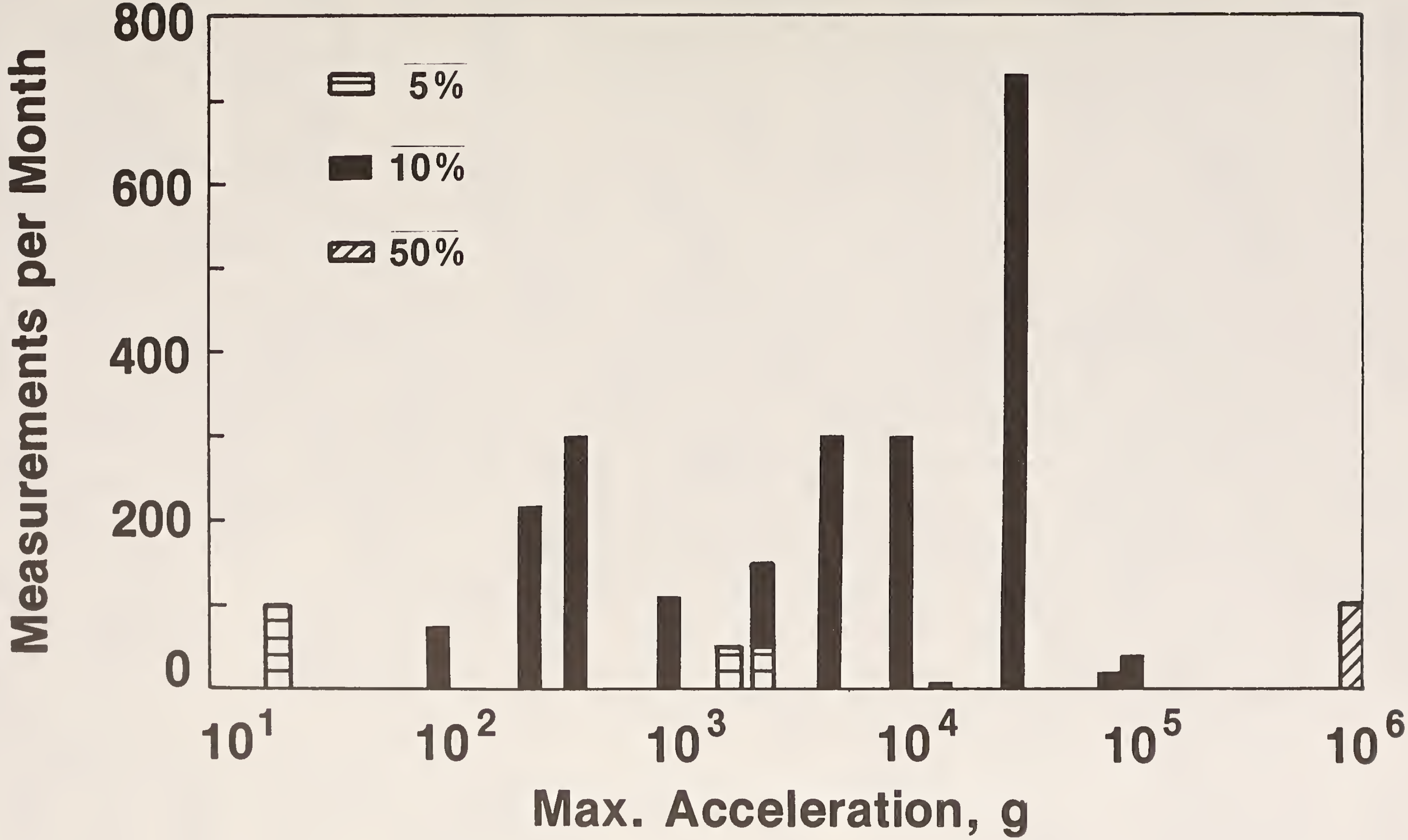

Figure 4 - Number of Items and Estimated Uncertainties vs. Max. Acceleration from Shock User Survey

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Same as item 6.

10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

The use of obsolete, inadequate, or nonexistent calibration standards during weapons system development and acquisition make DoD and its contractors unable to validate system performance legally during testing, evaluation and production acceptance. To correct current weakness and to meet the DoD calibration requirements of the immediate future in the area of mechanical shock new accelerometer calibration standards must be produced and existing standards must be improved. This report describes the results of a survey of various government agencies and government contractors who are actively engaged in the measurement of shock motions of 100 g or higher. As part of the effort to establish current needs for the calibration of accelerometers, a study was made of the accuracy requirements in various engineering applications for the measurement of shock motions up to 200 000 g, and an evaluation was made of the accuracy required to calibrate such transducers for various ranges of accelerations. Based on this study, several recommendations are made for improving the state of calibration standards for mechanical shock accelerometers.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

Accelerometer calibration standards; calibration requirements; mechanical shock transducers; military specifications; nonlinear effects; pyrotechnic shock; shock accelerometer users; transducer manufacturers

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