Designation: E2963 – 22

Standard Test Method for Laboratory Measurement of Acoustical Effectiveness of Ship Noise Treatments Laboratory Measurement of Acoustical Effectiveness for Marine Bulkhead and Deck Treatments[1]

This standard is issued under the fixed designation E2963; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

This test method is designed to measure the acoustical effectiveness of treatments that are intended to reduce airborne noise on ships. Such treatments would be applied to compartment structural partitions such as bulkheads, decks, and side shells. To fully characterize the acoustical performance of a treatment, five parameters must be assessed: transmission loss, radiation efficiency, acceptance, absorption, and damping. This test method focuses on the assessment of the first three of these parameters. Tests discussed in this method are based on the Test Method E90 setup and procedure. This test method is not intended to be a replacement of Test Method E90; conversely, this method builds on the E90 method that is now well established. Similarly, this test method does not replace absorption testing discussed in Test Method C423, nor damping testing discussed in Test Method E756. The use of these standards is strongly encouraged to assess absorption and damping, respectively, if these are the primary features of the noise control material.

1. Scope

1.1 This test method covers the laboratory measurement of the acoustical effectiveness of treatments installed on ship bulkheads, decks, and side shells. Measurements are focused on assessing changes in transmission loss, radiation efficiency, and acceptance that occur when treatments are applied. Measurements of changes to absorption and damping are addressed in Appendix X1 and Appendix X2, respectively.

1.2 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.4 Any material that is to be installed on a marine division must meet appropriate fire, combustibility, and other applicable SOLAS, USCG, IMO, Navy, or other required non-acoustical standards and specifications. See Appendix X3 for additional information.

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C423 Test Method for Sound Absorption and Sound Absorption Coefficients by the Reverberation Room Method

C634 Terminology Relating to Building and Environmental Acoustics

E90 Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions and Elements

E756 Test Method for Measuring Vibration-Damping Properties of Materials

[1] This test method is under the jurisdiction of ASTM Committee E33 on Building and Environmental Acoustics and is the direct responsibility of Subcommittee E33.10 on Structural Acoustics and Vibration.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

2.2 *ANSI Standards:*[3]

ANSI S1.4-1983 (R2006) Specification for Sound Level Meters

ANSI S1.6-1984 (R2011) Preferred Frequencies, Frequency Levels, and Band Number for Acoustical Measurements

ANSI S1.8-1989 (R2011) ,Reference Quantities for Acoustical Levels

ANSI S1.11-2004 (R2009) Specification for Octave-Band and Fractional-Octave-Band Analog and Digital Filters

ANSI S1.43-1997 (R2007) Specifications for Integrating-Averaging Sound Level Meters

2.3 *ISO Stadnard:*[4]

ISO 16063-1:1998 , Methods for the Calibration of Vibration and Shock Transducers

3. Terminology

3.1 *Definitions*—Terms used in this standard are defined either in Terminology C634 or within this standard. The definition of terms explicitly given within this standard take precedence over definitions given in Terminology C634. The definitions within Terminology C634 and this standard take precedence over any other definitions of defined terms found in any other documents, including other documents that may be referenced in this standard.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *acceptance, n*—a measure of the vibration velocity level induced in a structure that is exposed to a diffuse sound field composed of one or more frequencies (see Eq 6).

3.2.2 *acoustical effectiveness, n*—a measure of the change in a particular acoustical parameter that is created by the addition of a material to the base structure.

3.2.3 *radiation efficiency, n*—a measure relating the sound pressure level in a diffuse sound field that is produced by a vibrating structural surface, referenced to a specified vibration velocity level, when that surface is moving in an oscillatory motion at one or more frequencies (see Eq 8).

3.2.4 *test or 'base' structure, n*—The structure representing a bulkhead, deck, or shell of a ship.

3.2.4.1 *Discussion*—The base structure is typically constructed with steel or aluminum stiffened plating, though other construction types are possible. This is the structure to which treatments are applied.

3.3 *Symbols:*

A = room constant, m^2
S = area of partition (structure under test), m^2
a = acceleration, m/s^2
c = speed of sound in air, m/s
dB = decibels
f = frequency, Hz
p = pressure, Pa
v = velocity, m/s
L_a = vibration acceleration level, dB re: 10 $\mu m/s^2$
L_p = sound pressure level, dB re: 20 μPa. Lv – velocity level, dB re: 10 nm/s (that is, 10^{-8} m/s)
L_A = acceptance in decibels referenced to 20 μPa/10 nm/s
L_σ = radiation efficiency in decibels
TL = transmission loss in decibels
ΔX = change in the quantity "X" between treated and non-treated test cases
α = sound absorption coefficient
η = loss factor, (no dimensions)
ρ = density, kg/m^3

3.4 All levels expressed in decibels have a reference quantity. A level expressed in decibels is 10 times the common logarithm of the ratio of a squared quantity divided by a squared reference quantity. For example, the reference quantity for sound pressure level is 20 micropascals. The abbreviated level is written as dB re: 20 μPa

4. Summary of Test Method

4.1 The effectiveness of a given treatment is determined by comparing the acoustical properties of a given structure with and without the treatment applied. Measurements are first performed on a 'baseline' test structure (that is, without the treatment in place). The treatment is then added to the structure and tests are repeated. The differences in acoustical parameters between the treated and non-treated structures determine the acoustical effectiveness of the treatment.

4.2 The general test setup discussed in Test Method E90 shall be used. Two adjacent reverberation rooms are arranged with an opening between them in which a test partition is installed.

4.3 Transmission loss, acceptance, and radiation efficiency (as well as absorption and damping) are all functions of frequency, and measurements are made in a series of frequency bands.

4.4 For measurement of transmission loss, Test Method E90 shall be used to test both the treated and non-treated structures. Fig. 1 presents a schematic diagram of the test setup, for reference purposes.

4.5 For the measurement of acceptance, the same test setup discussed in Test Method E90 is used with accelerometers attached to the test structure. An approximately diffuse sound field is produced in the source room; the space- and time-averaged sound pressure levels are measured in this room. The vibration levels of the test structure are simultaneously measured to produce a space- and time-averaged vibration level of the structure (see Fig. 2). These quantities (sound pressure level and test structure vibration level) are combined to determine the acceptance for the test structure, as shown in Section 13.

4.6 For the measurement of radiation efficiency, the same test setup discussed in Test Method E90 is used. Accelerometers are located on the test structure along with an electromechanical vibration exciter. The vibration exciter drives the structure, which then radiates sound into the receiver room. The sound field produced in this room is considered to be diffuse. The room's space- and time-averaged sound pressure levels are measured, as well as the structure's space- and

[3] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

[4] Available from International Organization for Standardization (ISO), 1, ch. de la Voie-Creuse, CP 56, CH-1211 Geneva 20, Switzerland, http://www.iso.org.

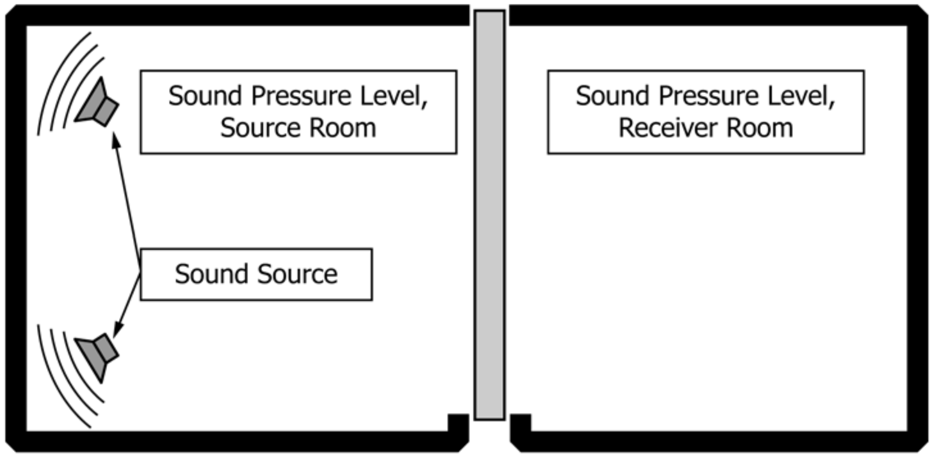

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FIG. 1 Illustration showing the conceptual setup for transmission loss testing (based on Test Method E90)

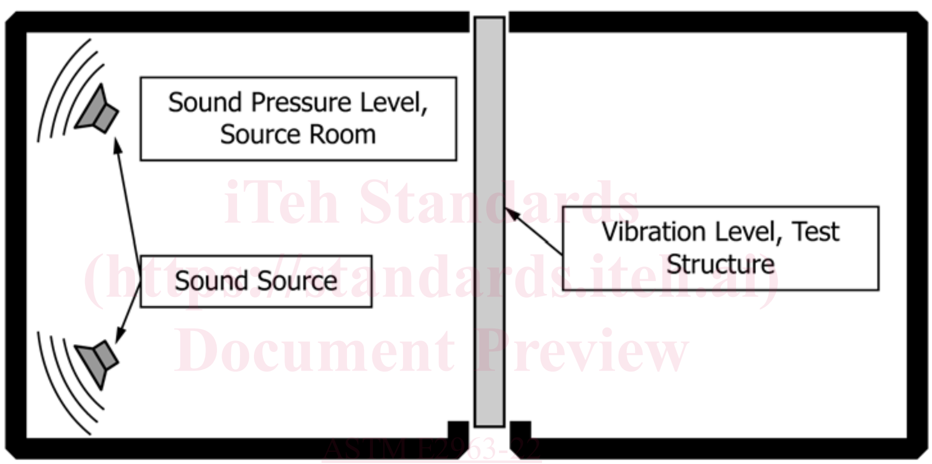

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FIG. 2 Illustration Showing the Conceptual Setup for Acceptance Testing (Note the Similarities to Fig. 1)

time-averaged vibration level (see Fig. 3). These quantities, along with the sound absorption in the receiving room and the area of the specimen, are combined to determine the radiation efficiency for the test structure, as shown in Section 13.

4.7 Room absorption measurements are necessary to calculate transmission loss and radiation efficiency. The change in room absorption between the treated and non-treated tests will be directly related to any absorption provided by the treatment. While treatment absorption measurements are formally covered by Test Method C423 it is convenient to use the measured room absorption from transmission loss and radiation efficiency tests to determine the effect of the treatment on absorption. This is discussed in more detail in Appendix X1. These measurements shall not replace measurements described in Test Method C423 as the results would be different. However, they can provide a useful and convenient indication of the absorption of a treatment, which may have sufficient accuracy for engineering applications (see Appendix X1).

4.8 The effect of a treatment on the structure's total damping loss factor requires a different test setup than that described in Test Method E90. If the treatment is expected to provide noise reduction via changes to the structure's damping, an assessment of the treatment's damping characteristics should be made using Test Method E756.

5. Significance and Use

5.1 To fully understand the effects of a given treatment, five acoustical factors (transmission loss, acceptance, radiation efficiency, absorption, and damping) must be characterized. For example, only knowing the effect of a given treatment on transmission loss will not allow the acoustical designer or engineer to assess its impacts on propagation of vibration (among other effects), which is an important path to consider for large machinery items and propeller excitation.

5.2 It is necessary to have a common definition of acoustical performance and test procedure to determine all five acoustical factors for ship's treatments so that the performance of different treatment types, as well as the same treatment type from different manufacturers, can be compared.

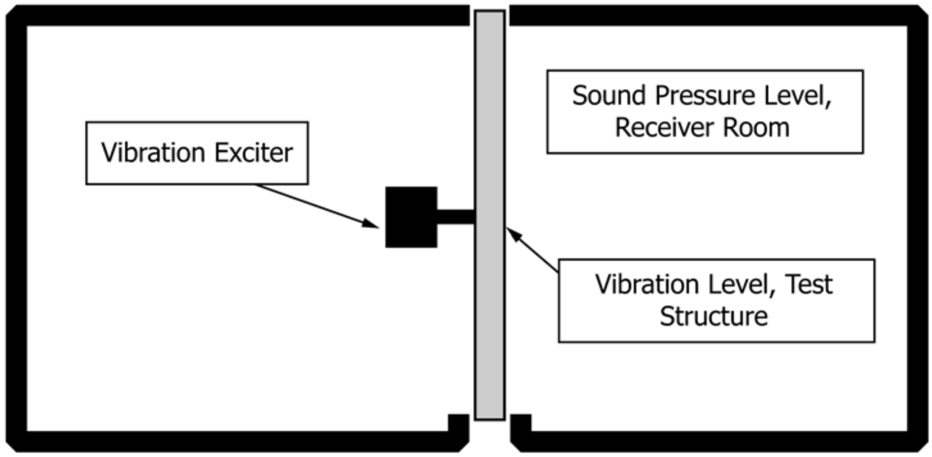

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FIG. 3 Illustration Showing the Conceptual Setup for Acceptance Testing (Note the Similarities to Fig. 1)

5.3 In some cases, particularly for damping treatments, the effect of the treatment will be dependent on the non-treated structure's material and geometry and other non-acoustic factors such as environmental conditions (that is, temperature). To fully characterize a treatment it may be necessary to test a range of base constructions. For reasons of practicality, convenience, or economy, it may be sufficient to test only one to three constructions to achieve an understanding of the material performance in a range of practical situations. Additional discussion is provided in Annex A1.

6. Test Apparatus

6.1 The room requirements of Test Method E90 shall be used for the testing of transmission loss, acceptance, and radiation efficiency. Special attention may be needed when testing the treated structure to meet the signal-to-noise ratio per Test Method E90.

6.2 Where the test structure is smaller than the opening between the source and receiver rooms, a filler wall shall be constructed as described in Test Method E90. Meeting the transmission loss requirements for this filler wall shall constitute meeting related requirements for acceptance and radiation efficiency.

6.3 The structure shall be constructed to be representative of actual bulkhead, deck, or shell structure to which the treatment will be applied. Often, a single treatment can be applied to many different structures and construction types; therefore, not all constructions can be practically tested. In such cases it is recommended that one to three 'reference' bulkheads be tested, as discussed in Annex A1, to establish a baseline material performance to which other materials can be readily compared. If treatment effectiveness is expected to change significantly with different bulkhead constructions then additional constructions shall be tested to better define the performance of the material.

6.4 Treatments shall be applied to the test structure as they would be in an actual ship installation. This includes the use of special mounting hardware or edge treatments, as applicable.

6.5 *Aging of Specimens*—Treatments that incorporate materials for which there is a curing process shall age for a sufficient interval before testing, as recommended by the manufacturer. In these cases, it may be convenient and practical to use separate test structures of identical construction to test the treated and non-treated conditions.

7. Test Signal Sources

7.1 *Signal Spectrum*—The sound and vibration signals used for these tests shall be random noise having a continuous spectrum within each test frequency band.

7.2 *Sound Sources*—Sound is generated in the rooms using loudspeaker systems. The requirements for sound sources defined in Test Method E90 shall be followed.

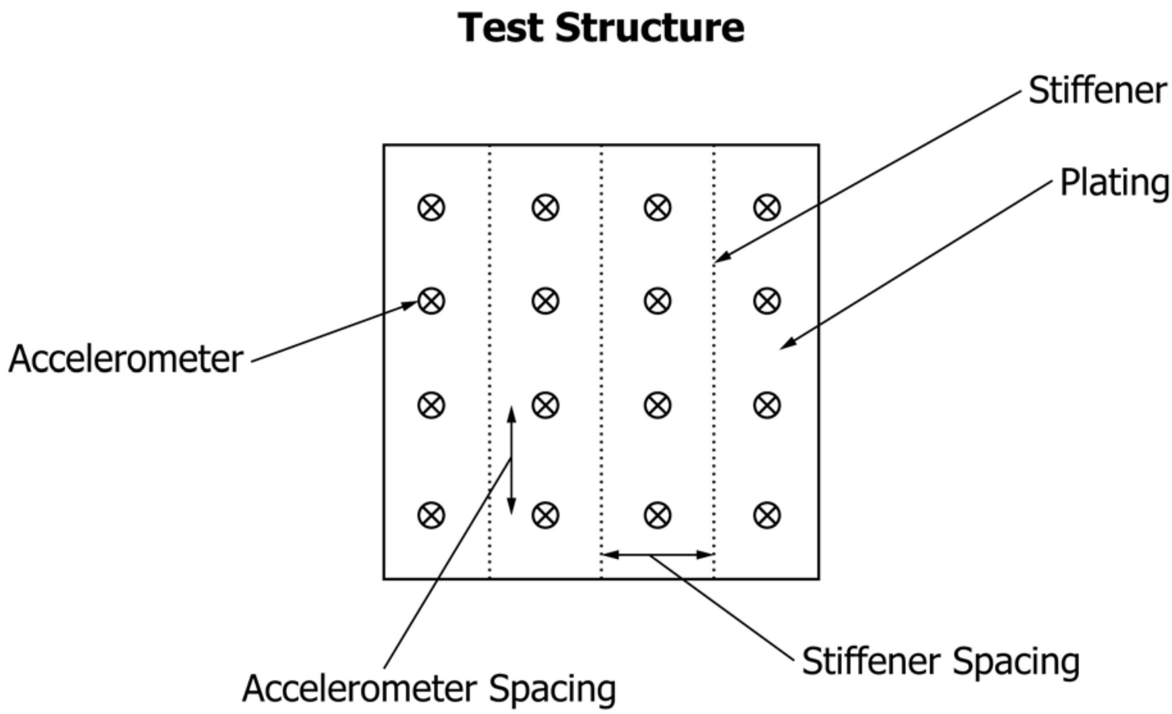
7.3 *Vibration Sources*—An electro-mechanical vibration exciter capable of producing vibration in the test frequency band shall be used. Note that multiple vibration exciters may be necessary to cover the entire test frequency range (see 11.2). Signals can be produced over the entire test frequency range or broken up into multiple frequency ranges as needed to meet the test requirements of this test method.

7.3.1 The vibration exciter must provide enough power to sufficiently excite the test structure to *(a)* generate noise levels in the receiver room that are at least 10 dB above background noise levels and *(b)* generate vibration levels that are at least 10 dB above the background vibration levels of the test structure.

7.3.2 Attach or mount the vibration exciter to a stiffener located away from the edge of the test structure. The closest distance between the vibration exciter and the edge of the structure shall be no smaller than the distance between stiffeners. A location near the middle of the stiffener is preferable for most test structures.

7.3.3 If the 'unstiffened' side of the structure is excited, the vibration exciter should be mounted as close as possible to the location of a stiffener instead of between stiffeners.

7.3.4 Excitation should be oriented normal to the plating. The vibration exciter location must be the same for tests of treated and non-treated structures.



Note that stiffener spacing is approximately the same as the accelerometer spacing.

FIG. 4 Example of accelerometer measurement locations

7.3.5 When treatments are applied to only one side, the vibration exciter shall be attached to the non-treated side. When treatments are applied to both sides, the vibration exciter shall be attached directly to the base structure. Minimal movement or removal of treatments should be employed to accommodate vibration exciter attachment.

8. Microphone Requirements

8.1 Microphone requirements and placement described in Test Method E90 shall be followed.

9. Accelerometer Requirements

9.1 Accelerometers are used to measure the vibration of the structure to determine the acceptance and radiation efficiency. Systems employing single or multiple accelerometers can be used, though multiple accelerometer systems are recommended.

9.2 *Accelerometer Performance Requirements*—Use accelerometers and data acquisition systems that are stable (as defined in ANSI S1.4, Section 3.10 for a Type 1 measurement system) and have a uniform response in the frequency range of measurement. Where multiple accelerometers are used, they should be of the same model.

9.3 *Accelerometer Mass*—Accelerometers should be as light as possible in order to avoid mass loading effects (**1**).[5] Accelerometers must have a mass of 15 g or less.

9.4 *Calibration*—Each accelerometer shall have been calibrated over the range of test frequencies to ensure the required accuracy per ISO 16063. A record shall be kept of the calibration data and dates of calibration. Field calibration of the entire measurement system for at least one frequency shall be made at least once during each day of testing.

9.5 Field calibration shall be made using a vibration calibrator. The reading of the acceleration level should match the output of the calibrator, adjusted for any gains or sensitivities of the system. Accelerometer sensitivity differences greater than 10 % relative to the nominal manufacturer sensitivity shall not be used.

9.6 *Accelerometer Positions*—Accelerometers shall be mounted to the test structure itself, not to the treatment. When necessary, portions of the treatment can be moved or removed to allow for accelerometer access, as long as such removal does not account for more than 1 % of the total treatment surface area and does not otherwise compromise its effectiveness. When treatments are applied to only one side of a test structure, accelerometers should be applied to the untreated side.

9.6.1 Primary accelerometer positions shall be on plating between stiffeners.

9.6.2 Accelerometer locations may be spaced by approximately the same distance as the smallest distance between adjacent stiffeners. Accelerometers should be located no closer than half the stiffener spacing from the edges of the test structure. For practical bulkhead configurations (see Annex A1), this would result in approximately 10 to 20 locations. An example is shown in Fig. 4.

[5] The boldface numbers in parentheses refer to a list of references at the end of this standard.

9.6.3 Alternatively, a pseudo-random placement can be used, as shown in Fig. 5. This involves dividing the test structure into "Accelerometer Placement Areas" and randomly locating one accelerometer within each area. The Accelerometer Placement Areas should have dimensions that are approximately equal to the stiffener spacing; a buffer of at least 10 % of the stiffener spacing shall be provided adjacent to any stiffeners and the edge of the test structure. This will ensure that accelerometers are not placed directly on stiffeners.

9.6.4 Additional accelerometer locations can be used as deemed necessary. Additional locations would be employed if significant variations in vibration levels were seen in any frequency band between adjacent accelerometer locations (that is, variations that would cause deviations to the measured changes that are greater than the expected accuracy discussed in Section 15). In addition, measurement locations on stiffeners can be utilized if deemed to have significant vibration levels relative to plating locations. All accelerometer locations must be identical for tests of treated and non-treated test structures.

9.6.5 During radiation efficiency testing, measurements shall not be performed directly at or immediately adjacent to the vibration exciter position. Accelerometers should be located at least ½ of the stiffener spacing away from the vibration exciter.

9.7 *Accelerometer Measurement Direction*—Accelerometers should be applied to the structure so that they measure vibration in the direction normal to the plate surface (that is, out-of-plane direction).

10. Hazards

10.1 Test structures will be heavy. Care must be taken when assembling, moving, and installing test structures. Proper mechanical lifting equipment shall be used at all times when moving test structures. All personnel shall maintain a safe distance from test structures while they are being moved. When stationary, test structures must be properly secured in place.

11. Frequency Range and Bandwidth for Analysis

11.1 The frequency range and bandwidth for all tests shall be the same as that specified in Test Method E90, except as specified below.

11.2 *Standard Test Frequencies*—Measurements shall be made in one-third-octave bands with mid-band frequencies specified in ANSI S1.6 from 100 to 10 000 Hz. It is often desirable that the frequency range be extended to include bands below 100 Hz. Many applications require information on low frequency acoustical performance and laboratory operators are encouraged to collect and report information down to at least 63 Hz where feasible. Note that larger room volumes are recommended when measuring at lower frequencies (see Test Method E90).

12. Procedure

12.1 *Measurement Overview*—Measurements of transmission loss and acceptance can be performed simultaneously. Measurements of radiation efficiency must be performed separately. Measurements of sound absorption and damping are performed separately, as discussed in Appendix X1 and Appendix X2, respectively. Sound sources and vibration exciters must not be used at the same time during a test.

12.1.1 Measurements of transmission loss are performed in accordance with Test Method E90.

12.1.2 Measurements of acceptance are performed by generating an acoustic signal in the source room and measuring the resulting sound pressure level in the source room as well as the vibration of the test structure. Note that when performing a measurement of acceptance of the treated test structure, the treated side is typically in the source room.

12.1.3 Measurements of radiation efficiency are performed by energizing the vibration exciter and measuring the resulting vibration of the test structure as well as the sound pressure level in the receiver room. Note that when performing a measurement of radiation efficiency of the treated test

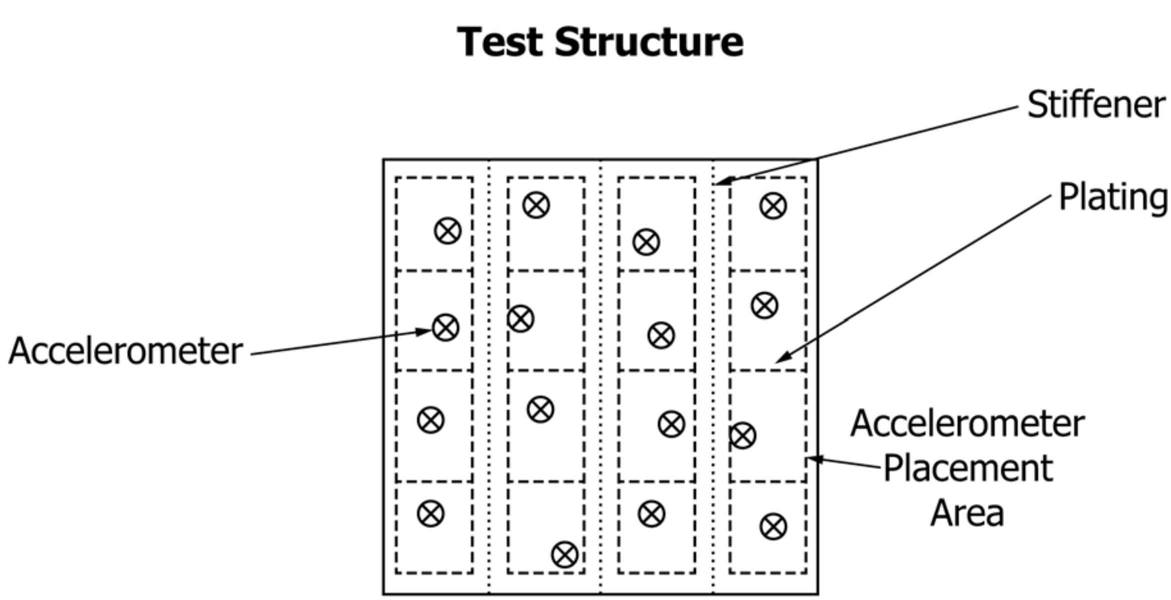


FIG. 5 Example of pseudo-random accelerometer measurement locations

structure, the treated side is typically in the receiver room unless significant changes to damping loss factor are expected. The vibration exciter must not be located in the receiver room, as noise from the vibration exciter itself may adversely impact the test results.

12.1.4 Given the above test descriptions, it will be advantageous to allow both test rooms to be used interchangeably as the source and receiver room. For example, if a treatment is applied to one side of a test structure, the treated side should be in the source room for the acceptance test and the receiver room for the radiation efficiency test. This can be accomplished by applying the treatment on the side of the test structure facing the room containing the sound source and using microphones in both rooms. In these tests, the vibration exciter and accelerometers would be located on the non-treated side of the test structure. It may be convenient to install sound sources in both rooms, as room absorption measurements would need to be performed in both spaces.

12.2 *Measurement of Average Sound Pressure Levels* $<L_1>$ *and* $<L_2>$—Measurements of sound pressure levels within the source room ,$<L_1>$ and $<L_2>$ room shall be performed in accordance with Test Standard E90.

12.3 *Measurement of Time Average Vibration Acceleration Levels,* L_a—Acceleration levels at all positions shall be measured and averaged over the same minimum averaging time used for stationary microphone measurements, as described in Test Method E90. This shall be done for both acceptance and radiation efficiency measurements.

12.4 *Background Noise and Vibration*—Background noise shall be measured in the source and receiver rooms in accordance with Test Method E90. Background vibration levels shall be measured using a similar procedure. It is important that background noise be measured using the same gain or 'range' settings in the data acquisition system as is used during measurements with sound or vibration sources operational, as this will include any electrical noise in the system.

12.4.1 Noise and vibration levels measured with the sound or vibration sources operational must be corrected for background noise if the measured levels are less than 10 dB above background. All measurements should be at least 5 dB above background. Corrections for sound levels within 5 to 10 dB of background shall use the following formula:

$$L_s = 10Log\left[10^{L_{sb}/10} - 10^{L_b/10}\right] \quad (1)$$

where:

L_b = background level, dB
L_{sb} = level of signal and background combined, dB, and
L_s = adjusted signal level, dB.

12.4.2 If the output of the sound sources cannot be increased so the combined level is at least 5 dB above the background level, then subtract 2 dB from the combined level and use this as the corrected signal level. In this case, the measurements can be used only to provide an estimate of the lower limit of the measured acoustical parameter. Identify such measurements in the test report.

12.5 *Determination of Room Absorption, A*—The room absorption in the receiver room must be measured to calculate transmission loss and radiation efficiency. As noted in 4.7, a measurement of absorption can be used to assist with the definition of the acoustical performance of a treatment. The measurement of room absorption shall follow Test Method E90. The receiver room may be different for tests of transmission loss and radiation efficiency. In either case, it will be desirable to measure the room constant in the room containing the treatment (see Appendix X1).

13. Calculation

13.1 All calculations shall be performed for each one-third-octave band test frequency.

13.2 For each measurement of airborne noise, the space and time averaged sound pressure level shall be calculated in accordance with Test Method E90.

13.3 For each measurement of vibration, the measured acceleration level shall be converted to velocity using the equation:

$$L_v = L_a - 20{*}Log(2\ \pi\ f) + 60 \quad (2)$$

where:

L_v = the vibration velocity level in dB re: 10 nm/s,
L_a = the vibration acceleration level in dB re: 10 μm/s^2, and
f = the one-third-octave band center frequency.

The space and time averaged vibration velocity level shall be calculated in each one-third-octave band using:

$$\langle L_v \rangle = 10\ Log\left[\frac{1}{n}\sum_{i=1}^{n} 10^{L_i/10}\right] \quad (3)$$

where:

$<L_v>$ = the space and time average vibration velocity level, dB re: 10 nm/s,
n = the number of accelerometer locations, and
Li = the time average vibration velocity level of measurement position i, dB re: 10 nm/s.

13.4 *Transmission Loss*—As per Test Method E90, the calculation of transmission loss for a structure under test uses the equation:

$$TL = \langle L_i \rangle - \langle L_2 \rangle + 10Log\left[\frac{S}{A_2}\right] \quad (4)$$

where:

TL = the transmission loss of the structure, dB,
$<L_1>$ = the time and space average sound pressure level in the source room, dB re: 20 μPa,
$<L_2>$ = the time and space average sound pressure level in the receiver room, dB re: 20 μPa,
S = the surface area of the test structure (plating only, not including stiffener areas), m^2, and
A_2 = the room constant for the receiver room, m^2.

13.4.1 To calculate the effect of the treatment on transmission loss, use the equation:

$$\Delta TL = TL_{Treat} - TL_{Non-Treat} \quad (5)$$

where: