METHOD 528.1

MECHANICAL VIBRATIONS OF SHIPBOARD EQUIPMENT (TYPE 1 – ENVIRONMENTAL AND TYPE II – INTERNALLY EXCITED)

CONTENTS

CONTENTS - Continued

FIGURES

TABLES

METHOD 528.1 ANNEX A
IDENTIFYING RESPONSE PROMINENCES TO BE INCLUDED IN ENDURANCE TESTING

CONTENTS - Continued

METHOD 528.1 ANNEX B
NOTES AND ENGINEERING GUIDANCE

ANNEX B TABLE

(This page is intentionally blank.)

METHOD 528.1

MECHANICAL VIBRATIONS OF SHIPBOARD EQUIPMENT (TYPE I – ENVIRONMENTAL AND TYPE II – INTERNALLY EXCITED)

NOTE: This Method incorporates the requirements of MIL-STD-167-1A and additional lessons learned. This method shall be considered a requirement for US Navy vessels, and guidance for other applications.

1. SCOPE.

1.1 Purpose.

This Method specifies procedures and establishes requirements for environmental and internally excited vibration testing of Naval shipboard equipment installed on ships (see Annex B, paragraphs 1e and f).

1.2 Applicability.

The test procedures specified herein are applicable to shipboard equipment subjected to mechanical vibrations on Navy ships with conventional shafted propeller propulsion, and can be tailored according to Paragraph 5.1 for non-conventional propulsor types such as waterjet or podded propulsors. For internal excitation caused by unbalanced rotating components of Naval shipboard equipment, use the balance procedure according to paragraph 5.2.2. For those mechanical vibrations associated with reciprocating machinery and lateral and longitudinal vibrations of propulsion systems and shafting, see MIL-STD-167-2A.

1.3 Classification.

The following types of vibration are covered in this Method:

a. Type I – Environmental Vibration.

b. Type II – Internally Excited Vibration.

1.4 Limitations.

See paragraph 1.2 for limitations.

2. APPLICABLE DOCUMENTS AND DEFINITIONS.

2.1 General.

The documents listed in paragraph 6.1 are specified in paragraphs 3, 4, or 5 of this Method. This paragraph does not include documents cited in other paragraphs of this Method, or recommended for additional information, or as examples. While every effort has been made to ensure the completeness of this list, document users are cautioned that they must meet all specified requirements of documents cited in paragraphs 3, 4, or 5 of this Method, whether or not they are listed.

2.2 Definitions.

a. **Acceptance authority**. As used in this Standard, the term "acceptance authority" means the government activity (or its designated representative) having approval authority to determine vendor compliance with the requirements of this Method.

b. **Amplitude, single**. See amplitude, vibratory displacement.

c. **Amplitude, vibratory displacement**. Vibratory displacement amplitude is the maximum displacement of simple linear harmonic motion from the position of rest. This is also referred to as single amplitude or peak amplitude and is the maximum positive value during a given interval. It is expressed in inches, mils (0.001 inch), or mm (0.001 meter).

d. **Balancing**. Balancing is a procedure by which the radial mass distribution of a rotor is adjusted so that the mass centerline approaches the geometric centerline of the rotor, and, if necessary, adjusted in order to ensure that the vibration of the journals or forces on the bearings, at a frequency corresponding to operational speed, are within specified limits.

e. **Balancing, multi-plane**. Multi-plane balancing refers to any balancing procedure that requires unbalance correction in more than two axially separated correction planes.

f. **Balancing, single-plane (static)**. Single-plane (static) balancing is a procedure by which the mass distribution of a rigid rotor is adjusted in order to ensure the residual static unbalance is within specified limits, and that requires correction in only one plane. (Note: Single-plane balancing can be done on a pair of knife edges without rotation of the rotor, but is now more usually done on centrifugal balancing machines.)

g. **Balancing, two-plane (dynamic).** Two-plane (dynamic) balancing is a procedure by which the mass distribution of a rigid rotor is adjusted in order to ensure that the residual unbalance in two specified planes is within specified limits.

h. **Critical speed.** Critical speed is the speed of a rotating system that corresponds to a natural frequency of the system.

i. **Environmental vibration.** Environmental vibration is vibratory force that is imposed on equipment installed aboard ships under all external conditions. The hydrodynamic force from the propeller blades interacting with the hull is usually the principal exciting force.

j. **Equipment.** Equipment is any rotating or non-rotating machine that is intended to be installed aboard ship.

k. **Grade, balance quality.** Balance quality grade, G, refers to the amount of permissible unbalance of a rotor. The balance quality grade is the product of the maximum permissible eccentricity (distance between the shaft axis and the rotor center of gravity (in mm)) and the rotational velocity (radians/sec). The units for balance quality grade, G, are mm/sec. By this definition, a particular grade rotor will be allowed a mass eccentricity ($e=G/\omega$), that is inversely proportional to the operating speed.

l. **Internally excited vibration.** Internally excited vibration is vibration of machinery generated by mass unbalance of a rotor.

m. **Isolation mount.** An isolation mount is a device used to attenuate the force transmitted from the equipment to its foundation in a frequency range.

n. **Mass unbalance.** Mass unbalance occurs when the mass centerline does not coincide with the geometric centerline of a rotor.

o. **Maximum design rpm.** Maximum design rpm is the highest shaft rpm for which the ship is designed.

p. **Method of correction**. A method of correction is a procedure, whereby the mass distribution of a rotor is adjusted to reduce unbalance or vibration due to unbalance, to an acceptable value. Corrections are usually made by adding materiel to, or removing it from, the rotor.

q. **Mode.** Natural Mode is the manner or pattern of vibration at a natural frequency, and is described by its natural frequency and relative amplitude curve.

r. **Plane, correction.** A correction plane is a plane transverse to the shaft axis of a rotor in which correction for unbalance is made.

s. **Plane, measuring.** A measuring plane is a plane transverse to the shaft axis in which the amount and angle of unbalance is determined.

t. **Residual unbalance.** Residual unbalance is unbalance of any kind that remains after balancing.

u. **Resonance.** Resonance is the structural response that occurs when a linear lightly damped system is driven with a sinusoidal input at its natural frequency in which the response prominence is greater than one.

v. **Response prominence**. Response prominence is a general term denoting a resonance or other distinct maximum, regardless of magnitude, in a transmissibility function, including local maxima that may exist at the frequency endpoints of the transmissibility function. Typically, a response prominence is identified by the frequency of its maximum response that is the response prominence frequency. A response prominence of a system in forced oscillation exists when any change, for both plus and minus increments however small, in the frequency of excitation results in a decrease of the system response at the observing sensor registering the maximum. A response prominence may occur in an internal part of the equipment, with little or no outward manifestation at the vibration measurement point, and in some cases, the response may be detected by observing some other type of output function of the equipment, such as voltage, current, or any other measurable physical parameter. Instruction on how to identify response prominences is provided in Annex A.

w. **Rotor, flexible**. A flexible rotor is one that does not meet the criteria for a rigid rotor and operates above its first resonance. The unbalance of a flexible rotor changes with speed. Any value of unbalance assigned to a flexible rotor must be at a particular speed. The balancing of flexible rotors requires correction in more than two planes. A rotor that operates above n resonances requires n+2 balance planes of correction. A rotor that operates between the second and third resonances, for example, requires 2+2 balance planes of correction.

x. **Rotor, rigid.** A rotor is considered to be rigid when its unbalance can be corrected in any two arbitrarily selected planes and it operates below its first resonance. After correction, its residual unbalance does not exceed the allowed tolerance, relative to the shaft axis, at any speed up to the maximum service speed and when running under conditions that approximate closely to those of the final supporting system.

y. **Simple harmonic motion**. A simple harmonic motion is a motion such that the displacement is a sinusoidal function of time.

z. **Test fixture resonance**. A test fixture resonance is any enhancement of the response of the test fixture to a periodic driving force when the driving frequency is equal to a natural frequency of the test fixture.

aa. **Transmissibility**. Transmissibility is the non-dimensional ratio of the response amplitude in steady-state forced vibration to the excitation amplitude. The ratio may be one of forces, displacements, velocities, or accelerations. Transmissibility is displayed in a linear-linear plot of transmissibility as a function of frequency, or in tabular form. Instructions for determining and displaying transmissibility are given in paragraph 2.1 of Annex A.

bb. **Vibration resistance**. It is measured by mechanical impedance – how hard it is to make mechanical systems vibrate. It is a ratio of the exciting force to the velocity response. Low impedance implies low force and/or high velocity—a system that is easy to excite.

3. INFORMATION REQUIRED.

The following information is required to conduct and document vibration tests adequately. Tailor the lists to the specific circumstances, adding or deleting items as necessary. Although generally not required in the past, perform fixture and equipment modal surveys when practical. These data are useful in evaluating test results, and in evaluating the suitability of equipment against changing requirements or for new applications. These data can be particularly valuable in future programs where the major emphasis will be to use existing equipment in new applications. (When modal survey is ruled out for programmatic reasons, a simple resonance search can sometimes provide useful information.)

3.1 Pretest.

The following information is required to conduct vibration tests adequately.

a. General. See Part One, paragraphs 5.7 and 5.9, and Part One, Annex A, Task 405 of this Standard.

b. Specific to this Method.

(1) Test fixture requirements.

(2) Test fixture modal survey requirements / procedure.

(3) Test item/fixture modal survey requirements / procedure.

(4) Vibration exciter control strategy.

(5) Test tolerances.

(6) Requirements for combined environments.

(7) Test schedule(s) and duration of exposure(s).

(8) Axes of exposure.

(9) Measurement instrumentation configuration.

(10) Test shutdown procedures for test equipment or test item problems, failures, etc. (See paragraph 4.3.)

(11) Test interruption recovery procedure. (See paragraph 4.3.)

(12) Test completion criteria.

(13) Assure that test requirements (force, acceleration, velocity, displacement) can be met. Seek approval for variation if required. Document any variation.

(14) Allowable adjustments to test item & fixture (if any); **these must be documented in the test plan and the test report.**

(15) Check bolts and washers before, during (when changing direction of vibration), and after test. Ensure all bolts are proper grip length and that the washers are not rotating.

(16) Identify potential areas of high stress concentration. Consider composite and cast materials.

c. Tailoring. Necessary variations in the basic test parameters/testing equipment to accommodate LCEP requirements and/or facility limitations. Tailoring is a function of the ship's propulsion system and the environment. All tailoring of this test Method must be approved in accordance to the procurement specification before testing.

> **NOTE:** Modal surveys of both test fixtures and test items can be extremely valuable. Large test items on large complex fixtures are almost certain to have fixture resonances within the test range. These resonances result in large overtests or undertests at specific frequencies and locations within a test item. Where fixture and test item resonances couple, the result can be misleading. Similar problems often occur with small test items, even when the shaker/fixture system is well designed. In cases where the fixture/item resonance coupling cannot be eliminated, consider special vibration control techniques such as acceleration or force limit control.

3.2 During Test.

a. General. See Part One, paragraph 5.10, and Part One, Annex A, Tasks 405 and 406 of this Standard.

b. Specific to this Method.

(1) Document any adjustments to the test item and fixture identified by the test plan, including planned stopping points. (See also paragraph 4.3.3.)

(2) Document the vibration exciter control strategy used, e.g., single point response, multipoint response, force limit, waveform, etc.

(3) Refer to the test-specific plan to address any additional data that may be required during the test phase.

(4) Check bolts and washers during testing (including when changing direction of vibration). Ensure all washers are not rotating.

3.3 Post-Test.

The following post-test information shall be included in the test report:

a. General. See Part One, paragraph 5.13, and Part One, Annex A, Task 406 of this Standard.

b. Specific to this Method.

(1) Summary and chronology of test events, test interruptions, and test failures.

(2) Discussion and interpretation of test events.

(3) Functional verification data.

(4) Test item modal analysis data.

(5) All vibration measurement data.

(6) Documentation of any test requirement variation (paragraph 3.1 b (14)).

(7) Any changes from the original test plan.

4. GENERAL REQUIREMENTS – TEST PROCESS.

a. **Notification of tests.** When specified (see Annex B, paragraph 2b), notification of Type I or Type II testing shall be made in accordance with DI-MISC-81624 (see Annex B, paragraph 3).

b. **Identification of component compliance.** When specified (see Annex B, paragraph 2c), the information verifying that the component complies with Type I and Type II testing shall be identified on the component drawing, the Test Report (DI-ENVR-81647) (see Annex B, paragraph 3), or an identification plate attached to the component.

c. **Disposition of tested equipment.** The requirements for tested equipment, fixturing, associated test records, and other documentation shall be as specified (see Annex B, paragraph 2d).

4.1 Test Facility.

Use a test facility, including all auxiliary equipment, capable of providing the specified vibration environments and the control strategies and tolerances discussed in paragraph 4.2. In addition, use measurement transducers, data recording and data reduction equipment capable of measuring, recording, analyzing, and displaying data sufficient to document the test and to acquire any additional data required. Unless otherwise specified, perform the specified vibration tests, and take measurements at standard ambient conditions as specified in Part One, paragraph 5.1.

4.2 Controls.

The accuracy in providing and measuring vibration environments is highly dependent on fixtures and mountings for the test item, the measurement system, and the exciter control strategy. Ensure all instrumentation considerations are in accordance with the best practices available (see paragraph 6.1, reference j). Careful design of the test set up, fixtures, transducer mountings, and wiring, along with good quality control will be necessary to meet the tolerances of paragraph 4.2.2 below.

4.2.1 Control Strategy.

Select a control strategy that will provide the required vibration at the required location(s) in or on the test item. Base this selection on the characteristics of the vibration to be generated and platform/ equipment interaction (see paragraph 1.3b above and Method 514.8, Annex A, paragraph 2.4). Generally, a single strategy is appropriate. There are cases where multiple strategies are used simultaneously.

4.2.1.1 Acceleration Input Control Strategy.

Input control is the traditional approach to vibration testing. Control accelerometers are mounted on the fixture at the test item mounting points. Exciter motion is controlled with feedback from the control accelerometer(s) to provide defined vibration levels at the fixture/test item interface. Where appropriate, the control signal can be the average (weighted average or maxima) of the signals from more than one test item/fixture accelerometer. This represents the platform input to the equipment, and assumes that the equipment does not influence platform vibration.

4.2.1.2 Force Control Strategy.

Dynamic force gages are mounted between the exciter/fixture and the test item. Exciter motion is controlled with feedback from the force gages to replicate field measured interface forces. This strategy is used where the field (platform/ equipment) dynamic interaction is significantly different from the laboratory (exciter/test item) dynamic interaction. This form of control inputs the correct field-measured forces at the interface of the laboratory vibration exciter and test item. This strategy is used to prevent overtest or undertest of equipment mounts at the lowest structural resonances that may otherwise occur with other forms of control.

4.2.1.3 Acceleration Limit Strategy.

Input vibration criteria are defined as in paragraph 4.2.1.1. In addition, vibration response limits at specific points on the equipment are defined (typically based on field measurements). Monitoring accelerometers are located at these points. The test item is excited as in paragraph 4.2.1.1 using test item mounting point accelerometer signals to control the exciters. The input criteria are experimentally modified as needed to limit responses at the monitoring accelerometers to the predefined limits. Changes to the specified input criteria are limited in frequency bandwidth and in level to the minimum needed to achieve the required limits.

4.2.1.4 Acceleration Response Control Strategy.

Vibration criteria are specified for specific points on, or within the test item. Control accelerometers are mounted at the vibration exciter/fixture interface. Monitoring accelerometers are mounted at the specified points within the item. An arbitrary low level vibration, controlled with feedback from the control accelerometers, is input to the test item. The input vibration is experimentally adjusted until the specified levels are achieved at the monitoring accelerometers. This strategy is commonly used with assembled aircraft stores where store response to the dynamic environment is measured or estimated. It is also applicable for other equipment when field measured response data are available.

4.2.1.5 Waveform Control Strategy.

This strategy is discussed in Method 525.2.

4.2.2 Tolerances.

Use the following tolerances unless otherwise specified. In cases where these tolerances cannot be met, achievable tolerances should be established and agreed to by the cognizant engineering authority and the customer prior to initiation of test. Protect measurement transducer(s) to prevent contact with surfaces other than the mounting surface(s).

4.2.2.1 Acceleration Spectral Density.

Carefully examine field measured response probability density information for non-Gaussian behavior. In particular, determine the relationship between the measured field response data and the laboratory replicated data relative to three sigma peak limiting that may be introduced in the laboratory test. The random vibration testing is restricted to combatants with skewed propellers. The alternating thrust of these propellers cannot exceed ±1.5 percent of full power mean thrust.

a. Vibration environment. The following discussion relates the measured vibration level to the specification level and, like the control system, does not consider any measurement uncertainty. The test tolerance should be kept to the minimum level possible considering the test item, fixturing, and spectral shape. Test tolerances of less than ±2 dB are usually readily attainable with small, compact test items (such as small and medium sized rectangular electronic packages), well-designed fixtures, and modern control equipment. When test items are large or heavy, when fixture resonances cannot be eliminated, or when steep slopes (> 20 dB/octave) occur in the spectrum, these tolerances may have to be increased. When increases are required, exercise care to ensure the selected tolerances are the minimum attainable, and that attainable tolerances are compatible with test objectives. In any case, tolerances should not exceed ±3 dB. These tolerances should be limited to a maximum of 5 percent of the test frequency range. Otherwise, change the tests, fixtures, or facilities so test objectives can be met. The rms level of the vibration test should not deviate more than ±10 percent from the required level.

b. Vibration measurement. Use a vibration measurement system that can provide acceleration spectral density measurements within ±0.5 dB of the vibration level at the transducer mounting surface (or transducer target mounting surface) over the required frequency range. Do not use a measurement bandwidth that exceeds 2.5 Hz at 25 Hz or below, or 5 Hz at frequencies above 25 Hz. Use a frequency resolution appropriate for the application (i.e., generally in wheeled vehicles, a resolution of 1 Hz is sufficient).

c. Swept narrow-band random on random vibration tests may require lesser degrees of freedom due to sweep time constraints.

d. Root mean square (RMS) "g". RMS levels are useful in monitoring vibration tests since RMS can be monitored continuously, whereas measured spectra are available on a delayed, periodic basis. Also, RMS values are sometimes useful in detecting errors in test spectra definition.

4.2.2.2 Peak Sinusoidal Acceleration.

a. Vibration environment. Validate the accelerometer(s) sensitivity before and after testing. Ensure the peak sinusoidal acceleration at a control transducer does not deviate from that specified by more than ±10 percent over the specified frequency range.

b. Vibration measurement. Ensure the vibration measurement system provides peak sinusoidal acceleration measurements within ±5 percent of the vibration level at the transducer mounting surface (or transducer target mounting surface) over the required frequency range.

4.2.2.3 Frequency Measurement.

Ensure the vibration measurement system provides frequency measurements within ±1.25 percent at the transducer mounting surface (or transducer target mounting surface) over the required frequency range.

4.2.2.4 Cross Axis Sensitivity.

Ensure vibration acceleration in two axes mutually orthogonal and orthogonal to the drive axis is less than or equal to 0.45 times the acceleration (0.2 times the spectral density) in the drive axis over the required frequency range. In a random vibration test, the cross axis acceleration spectral density often has high but narrow peaks. Consider these in tailoring cross-axis tolerances.

4.3 Test Interruption.

Test interruptions can result from multiple situations. The following paragraphs discuss common causes for test interruptions and recommended paths forward for each. Recommend test recording equipment remain active during any test interruption if the excitation equipment is in a powered state.

4.3.1 Interruption Due to Laboratory Equipment Malfunction.

a. General. See Part One, paragraph 5.11 of this Standard.

b. Specific to this Method. When interruptions are due to failure of the laboratory equipment, analyze the failure to determine root cause. It is also strongly advised that both control and response data be evaluated to ensure that no undesired transients were imparted to the test item during the test equipment failure. If the test item was not subjected to an over-test condition as a result of the equipment failure, repair the test equipment or move to alternate test equipment and resume testing from the point of interruption. If the test item was subjected to an over-test condition as a result of the equipment failure, the test engineer or program engineer responsible for the test article should be notified immediately. A risk assessment based on factors such as level and duration of the over-test event, spectral content of the event, cost and availability of test resources, and analysis of test specific issues should be conducted to establish the path forward. See Method 514.8, Annex A, paragraph 2.1 for descriptions of common test types, and a general discussion of test objectives.

4.3.2 Interruption Due to Test Item Operation Failure.

Failure of the test item(s) to function as required during operational checks presents a situation with several possible options. Failure of subsystems often has varying degrees of importance in evaluation of the test item. Selection of option a through c below will be test specific.

a. The preferable option is to replace the test item with a "new" one and restart the entire test.

b. An alternative is to replace / repair the failed or non-functioning component or assembly with one that functions as intended, and restart the entire test. A risk analysis should be conducted prior to proceeding since this option places an over-test condition on the entire test item except for the replaced component. If the non-functioning component or subsystem is a line replaceable unit (LRU) whose life-cycle is less than that of the system test being conducted, proceed as would be done in the field by substituting the LRU, and continue from the point of interruption.

c. For many system level tests involving either very expensive or unique test items, it may not be possible to acquire additional hardware for re-test based on a single subsystem failure. For such cases, a risk assessment should be performed by the organization responsible for the system under test to determine if replacement of the failed subsystem and resumption of the test is an acceptable option. If such approval is provided, the failed component should be re-tested at the subcomponent level.

> **NOTE**: When evaluating failure interruptions, consider prior testing on the same test item and consequences of such.

4.3.3 Interruption Due to a Scheduled Event.

There are often situations in which scheduled test interruptions will take place. For example, in a tactical transportation scenario, the payload may be re-secured to the transport vehicle periodically (i.e., tie-down straps may be re-secured at the beginning of each day). Endurance testing often represents a lifetime of exposure; therefore it is not realistic to expect the payload to go through the entire test sequence without re-securing the tie-downs as is done in a tactical deployment. Many other such interruptions, to include scheduled maintenance events, are often required over the life-cycle of equipment. Given the cumulative nature of fatigue imparted by dynamic testing, it is acceptable to have test interruptions that are correlated to realistic life-cycle events. All scheduled interruptions should be documented in the test plan and test report.

4.3.4 Interruption Due to Exceeding Test Tolerances.

Exceeding the test tolerances defined in paragraph 4.2.2, or a noticeable change in dynamic response may result in a manual operator initiated test interruption or an automatic interruption when the tolerances are integrated into the control strategy. In such cases, the test item, fixturing, and instrumentation should be checked to isolate the cause.

a. If the interruption resulted from a fixturing or instrumentation issue, correct the problem and resume the test.

b. If the interruption resulted from a structural or mechanical degradation of the test item, the problem will generally result in a test failure and requirement to re-test unless the problem is allowed to be corrected during testing. If the test item does not operate satisfactorily, see paragraph 5 for analysis of results and follow the guidance in paragraph 4.3.3 for test item failure.

5. DETAILED REQUIREMENTS.

5.1 Procedure I (Type I) – Environmental Vibration.

When Type I vibration requirements are specified (see Annex B, paragraph 2e), the test item shall be subjected to a simulated environmental vibration as may be encountered aboard Naval ships. This Method provides an amplitude sufficiently large within the selected frequency range to obtain a reasonably high degree of confidence that equipment will not malfunction during service operation.

a. For Type I vibration testing, this Method shall be used for equipment subjected to the vibration environment found on Navy ships with conventionally shafted propeller propulsion.

b. For Type I vibration testing this Method can be tailored for non-conventional Navy shafted propeller systems such as waterjet, podded, or other propulsor types, including those that have been designed to minimize blade-rate forces. The revised test Method shall be recommended by the purchaser and approved by the Government.

c. For equipment installed on ships with propulsion systems with frequency ranges not covered by Table 528.1-I, this Method shall not apply.

5.1.1 Basis of Acceptability.

For equipment that can be vibration tested, acceptability shall be contingent on the ability of the equipment to withstand tests specified, and the ability to perform its principal functions during and after vibration tests. Minor damage or distortion will be permitted during the test, providing such damage or distortion does not in any way impair the ability of the equipment to perform its principal functions (see Annex B, paragraphs 2f(1) and 2f(6)). Because of the numerous types of equipment covered by this Method, a definite demarcation between major and minor failures cannot be specified. Therefore, during testing acceptability a determination shall be made as to whether or not a failure is minor or major to determine whether testing should continue (see Annex B, paragraph 2f(2)). In general, a major failure is one that would cause mal-operation or malfunction of the item of equipment for a long period. Non-repetitive failures of such parts as connectors, knobs/buttons, certain fasteners, and wiring, that can be easily replaced or repaired, are generally considered minor failures. As such, the repair could be made and the test continued with no penalty to the remainder of the test item. The critical use of the equipment shall be considered when determining the category of failure; e.g., a failure of a part in a lighting circuit may be considered minor. The same failure in a control circuit may be major.

5.1.2 Test Procedures.

The tests specified herein are intended to expose equipment to:

a. Vibration magnitudes in prescribed frequency and amplitude ranges to reveal any critical response prominences (see paragraph 2.2v) or potential deficiencies.

b. A 2-hour minimum endurance test at the response prominence frequency or frequencies most seriously affecting its functional or structural integrity.

5.1.2.1 Testing Machine.

Vibration tests shall be made by means of any testing machine capable of meeting the conditions specified in paragraph 5.1.2.4, and the additional requirements contained herein. Means shall be provided for controlling the direction of vibration of the testing machine, and for adjusting and measuring its frequencies and the amplitude of vibration to keep them within prescribed limits. It is acceptable to use different machines for the vertical and horizontal directions. The testing machine, including table, actuator, and attachment fixtures, shall be rigid within the frequency range to be tested. This includes test fixture resonances that may result from interaction between the table and mounted test items. Testing machine rigidity shall be demonstrated by analysis, or by measuring transmissibility in accordance with paragraph 5.1.2.2d.

5.1.2.2 Additional Test Instrumentation.

Vibration measurement transducers such as accelerometers shall be installed on the test item to aid in the determination of response prominences during the exploratory and variable frequency vibration tests of paragraphs 5.1.2.4.2 and 5.1.2.4.3. The number, orientation, and placement of vibration transducers will depend upon the equipment under test, and should be sufficient to provide a suitable survey for identifying response prominences of the tested equipment and testing machine. When required, approval of transducer locations shall be obtained from the procuring activity (see Annex B, paragraph 2f(3)). Guidance below shall be used in the selection of measurement locations:

a. Measurements shall be made at locations corresponding to components or areas on the equipment of particular concern for operation of the equipment, whose failure would impair the ability of the equipment to perform its principal function. Such locations shall be determined prior to test.

b. Select a sufficient number of measurement locations such that the response of the test item is measured at locations near the base, top, and center of the test item to measure response prominences associated with global motion of the equipment. Attach these transducers to rigid areas of the test item representing major structural components such as the housing, shell, or body of the equipment.

c. The transducers shall be oriented to measure vibration in the direction of the vibration excitation provided for any given test. If necessary, transducers may be re-oriented between tests.

d. If the testing machine rigidity has not been demonstrated by analysis, a sufficient number of transducers shall be located on the testing machine to demonstrate that the testing machine is rigid over the frequency range of the test. At a minimum, locate these transducers at the point of force application to the table, and at the test item attachment interface(s) to the testing machine.

5.1.2.3 Methods of Attachment.

5.1.2.3.1 Shipboard Equipment.

For all tests, the test item shall be secured to the testing machine at the same points or areas of attachment that will be used for securing it shipboard. In case alternate attachment points or areas are specified, tests shall be performed using each attachment configuration. Equipment that is hard mounted (i.e., not isolation mounted) aboard ship shall be hard mounted to the testing machine. For equipment designed to be secured to a deck and a head brace support, a vertical bracket shall be used to simulate a bulkhead. The bracket shall be sufficiently rigid to ensure that its motion will be essentially the same as the motion of the platform on the testing machine. For isolation mounted shipboard equipment, see paragraph 5.1.2.3.4.

5.1.2.3.2 Shipboard Portable and Test Equipment.

Portable and test equipment that is designed for permanent or semi-permanent attachment to a ship structure shall be attached to the vibration testing machines in the same manner it is attached to the ship. Equipment that is not designed for permanent or semi-permanent attachment shall be secured to the testing machine by suitable means.

5.1.2.3.3 Orientation for Vibration Test.

Test items shall be installed on vibration testing machines in such a manner that the direction of vibration will be, in turn, along each of the three rectilinear orientation axes of the equipment as installed on shipboard – vertical, athwartship, and fore and aft. On a horizontal vibration-testing machine, the test item may be turned 90 degrees in the horizontal plane in order to vibrate it in each of the two horizontal orientations. At no time shall the test item be installed in any other way than its normal shipboard orientation.

5.1.2.3.4 Isolation Mountings.

For Type I testing of equipment to be installed shipboard on isolation mounts, testing shall be performed on isolation mounts or hard mounted to the testing machine, or as specified (see Annex B, paragraph 2f(4)). Type I testing of a particular test item on isolation mounts is valid only for the isolation mount type and configuration used during testing. Ensure the transmissibility across the mounts does not exceed 1.5 within the blade frequency range of 80 percent to 115 percent of design RPM. If equipment is tested for Type I vibrations hard mounted to the test fixture throughout the duration of the test, the test is valid for either hard mounted or isolation mounted shipboard installations, provided the isolation mounts are Navy standard mounts contained in MIL-M-17191, MIL-M-17508, MIL-M-19379, MIL-M-19863, MIL-M-21649, MIL-M-24476 (see paragraph 6.1, references a-f), or distributed isolation equipment (DIM).

5.1.2.3.5 Internal Isolation or Shock Mountings.

Equipment that incorporates other isolation mountings integrally within the equipment box (such as electronic cabinets) shall be tested with the internal mountings in the normal shipboard configuration or as specified (see Annex B, paragraph 2f(5)).

5.1.2.4 Vibration Tests.

Each of the tests specified shall be conducted separately in each of the three principal directions of vibration. All tests in one direction shall be completed before proceeding to tests in another direction. The test item shall be secured to the vibration table as specified in paragraph 5.1.2.3. If major damage occurs (see paragraphs 4.3 and 5.1.1), the test shall be discontinued, and the entire test shall be repeated following repairs or correction of deficiencies.

5.1.2.4.1 Equipment Operation.

Except as noted below, the test item shall be energized or operated to perform its normal functions (see Annex B, paragraph 2f(6)). Equipment that is difficult to operate on the testing machine shall be energized and subjected to operating conditions during the test. The test item shall then be operated after the test to demonstrate that there is no damage from the test (see Annex B, paragraph 2f(1)).

5.1.2.4.2 Exploratory Vibration Test.

To determine the presence of response prominences (see paragraph 2.2v) in the test item, it shall be secured to the vibration table and vibrated at frequencies from 4 Hz to 33 Hz, at a table vibratory single amplitude of 0.010 ± 0.002 inch (see paragraphs 5.1.2.4.4 and 5.1.2.4.5 for exceptions). The change in frequency shall be made in discrete frequency intervals of 1 Hz, and maintained at each frequency for about 15 seconds. Alternatively, a continuous frequency sweep with a rate of change of frequency not to exceed 0.067 Hz/second can be used. The frequencies at which functional or structural requirements are affected or violated and frequencies and locations at which response prominences occur shall be recorded, and these frequencies (rounded to the nearest integer frequency if discrete frequency intervals were not used) shall be considered as candidates for endurance testing (see Annex A).

5.1.2.4.3 Variable Frequency Test.

The test item shall be vibrated from 4 Hz to 33 Hz in discrete frequency intervals of 1 Hz, and at the amplitudes shown in Table 528.1-I (see paragraphs 5.1.2.4.4 and 5.1.2.4.5 for exceptions). At each integral frequency, the vibration shall be maintained for 5 minutes. The frequencies, at which functional or structural requirements are affected or violated, and frequencies and locations at which response prominences occur, shall be recorded. Note that because of increased amplitudes compared to those in paragraph 5.1.2.4.2, response prominences and effects on or violations of functional or structural requirements may show up in this test that were not uncovered in the exploratory vibration test. Therefore, the frequencies at which these response prominences and effects on or violations of functional or structural requirements occur shall also be considered as candidates for endurance testing (see Annex A).

Table 528.1-I. Vibratory displacement of environmental vibration.

Frequency range (Hz)	Table single amplitude (inch)
4 to 15	0.030 ±0.006
16 to 25	0.020 ±0.004
26 to 33	0.010 ±0.002

5.1.2.4.4 Exception.

Equipment intended for installation solely on a particular ship class need only be vibrated in the exploratory and variable frequency tests from 4 Hz to (1.15 x design rpm x number of propeller blades/60) rounded up to the nearest integer frequency or the maximum test frequency as specified by the purchaser and approved by the Government.

5.1.2.4.5 Alternative Test Amplitudes.

For equipment installed on ships with advanced isolation systems, low vibration propellers, or other reduced environment vibration conditions, the alternative test amplitudes can be reduced. A reduction in test amplitude shall be recommended by the purchaser and approved by the Government.

5.1.2.4.6 Endurance Test.

Endurance test frequencies are selected from the candidate list of endurance test frequencies developed during exploratory and variable frequency testing (see paragraphs 5.1.2.4.2 and 5.1.2.4.3). When specified (see Annex B, paragraph 2f(9)), selection of these frequencies is subject to approval. The test item shall be vibrated for a total period of at least 2 hours at the frequency determined to most seriously affect the functional or structural integrity of the equipment. Guidance for selecting response prominences from exploratory or variable frequency testing, for determining whether a response prominence is significant, and if the more serious response prominences can be identified, is given in Annex A. In cases where there are multiple response prominence frequencies selected, the duration of vibration testing at each frequency shall be in accordance with Table 528.1-II. If neither response prominences nor effects on equipment structural/functional performance are observed, this test shall be performed at 33 Hz or at the upper frequency as specified in paragraph 5.1.2.4.4. Ensure the amplitudes of vibration are in accordance with Table 528.1-I, unless otherwise specified (see paragraph 5.1.2.4.5). See Figure 528.1-1 for a graphical representation of the amplitudes in Table 528.1-I.

Table 528.1-II. Duration of endurance test in a given orthogonal direction at each test frequency.

Number of endurance test frequencies	Test time duration at each endurance test frequency	Total time
1	2 hours	2 hours
2	1 hour	2 hours
3	40 minutes	2 hours
4	40 minutes	2 hours, 40 minutes
n>2	40 minutes	40 x n minutes

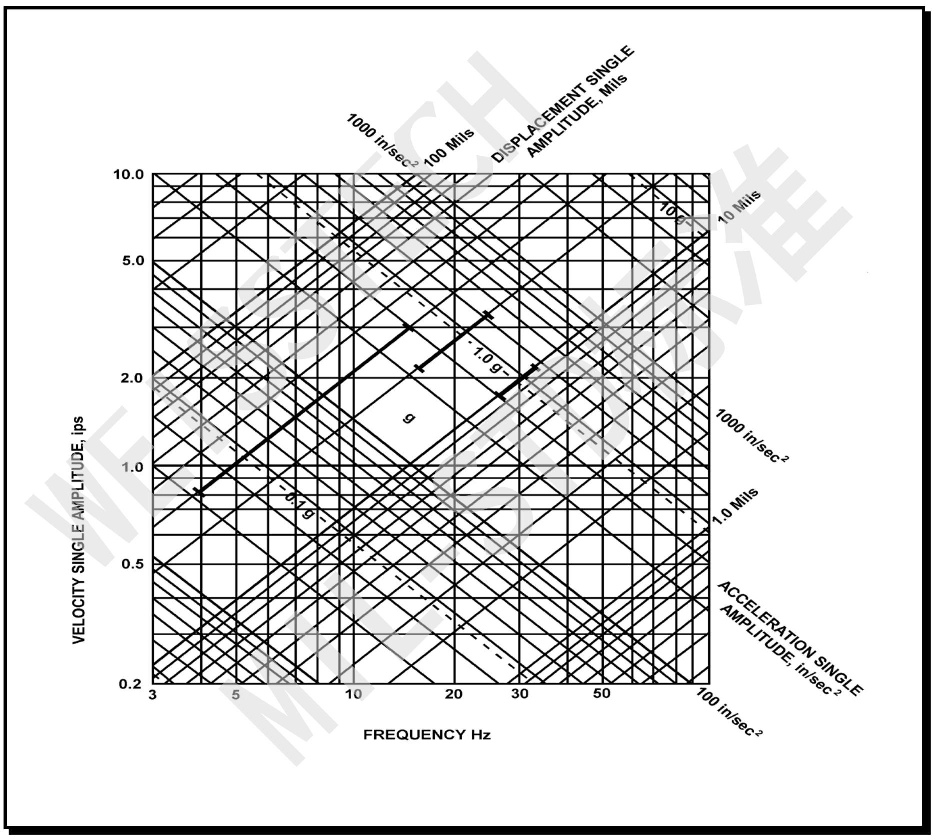

Figure 528.1-1. Type I environmental vibration limits (black bars represent a graphical presentation of Table 528.1-I expressed in displacement, velocity, and acceleration)

5.1.2.4.7 Endurance Test for Mast Mounted Equipment.

Equipment intended for installation on masts, such as radar antennae and associated equipment, shall be designed for a static load of 2.5g (1.5g over gravity) in vertical and transverse (athwartship and longitudinal) directions to compensate for the influence of rough weather. In addition, the test item shall be vibrated for a total period of at least 2 hours at the response prominences chosen by the test engineer. When specified (see Annex B, paragraph 2f(9)), selection of these frequencies is subject to approval. If no response prominences were observed, this test shall be performed at 33 Hz, unless excepted by paragraph 5.1.2.4.4, in which case use the maximum frequency specified in paragraph 5.1.2.4.4 shall be used. The amplitudes of vibration shall be in accordance with Table 528.1-III.

Table 528.1-III. Vibratory displacement of environmental vibration for mast mounted equipment.

Frequency Range (Hz)	Table Single Amplitude (inch)
4 to 10	0.100 ± 0.010
11 to 15	0.030 ± 0.006
16 to 25	0.020 ± 0.004
26 to 33	0.010 ± 0.002

5.1.2.5 Test Documentation.

5.1.2.5.1 Test Plan.

When specified (see Annex B, paragraph 2b), an equipment test plan shall be prepared for Type I tests in accordance with DI-ENVR-81647 (see Annex B, paragraph 3). The test plan shall specify, describe, or define all requirements, and shall be approved by the acceptance authority prior to the test as specified (see Annex B, paragraph 2f(10)).

5.1.2.5.2 Test Report.

A test report (see Annex B, paragraph 2b) for Type I tests shall be prepared in accordance with DI-ENVR-81647 (see Annex B, paragraph 3), and shall be approved by the acceptance authority as specified (see Annex B, paragraph 2f(10)).

5.1.3 Exemption.

If equipment size, weight, or center-of-gravity precludes testing on existing vibration facilities, the test item may be qualified by analysis or individually testing integral parts of the equipment, as approved by the acceptance authority. To facilitate this analysis process, the equipment could be shock tested to determine the natural frequencies. If the measured frequencies do not clear the blade rate by 25 percent, the equipment should be stiffened, and thereby, its vibration resistance increased.

5.1.4 Extension of Previous Testing.

Equipment that is identical or similar to previously tested equipment may qualify for an extension of the previously approved test. The equipment for which the testing is to be extended must meet all of the following criteria:

a. The tested equipment and the proposed extension equipment are made of the same or similar equipment, and manufactured using the same or similar processes.

b. The mass of the proposed extension equipment is no more than 10 percent greater than the mass of the tested equipment.

c. The location of the center of gravity of the proposed extension equipment is within 10 percent of the location of the center of gravity of the tested equipment.

5.1.4.1 Extension Documentation.

A request for extension of previously approved testing must be approved by the acceptance authority and must contain the following:

a. Detailed drawings of both the tested equipment and proposed extension equipment.

b. A copy of the test report for the tested equipment.

c. A detailed comparison of the differences in equipment and design showing that the proposed extension equipment has equal or greater vibration resistance than the tested equipment. This comparison should include at a minimum the information requested in paragraphs 5.1.4a, b, and c.

5.1.5 Alignment Criteria.

a. Equipment foundations should be such that they are devoid of natural frequencies within 25 percent of blade rate. If this guideline is not met, alignment issues will arise. That is, a tracker will not be able to home in on a target.

b. Equipment foundation response should not exceed 1/7th of the vibration displacement of environmental vibration. For combatants with an alternating thrust between ±1 and ±1.5 percent, Standardization Activity SH (NAVSEA 05P12) can allow a response of up to 2/7ths. If this guideline is not met, alignment issues can arise.

c. In order to reduce tracker alignment issues, a 57 mm gun, for example, should be designed with a total foundation impedance of 400 lb sec/in.

d. Superstructure deck response should not exceed 1/7th of vibratory displacement of environmental vibration for the mast mounted equipment. If this guidance is not met, the tracker can lose control with the satellite.

5.2 Procedure II (Type II) – Internally Excited Vibration.

Unless otherwise specified (see Annex B, paragraph 2e), Type II balance and vibration requirements shall apply to the procurement of rotating machinery. This does not apply to suitability from a noise standpoint, nor does it apply to reciprocating machinery. Special vibration and balance requirements may be specified (see Annex B, paragraph 2g(1)). The limitations set forth herein may also be used as criteria on overhaul tolerances, but should not constitute a criterion for the need for overhaul.

5.2.1 Basis of Acceptability.

All rotating machinery shall be balanced to minimize vibration, bearing wear, and noise. Types of balancing shall be as specified in Table 528.1-IV. Machinery with rigid rotors shall meet the limits of allowable residual unbalance given in paragraph 5.2.2.2. For machinery with rotors that are unable to meet the balance requirements of rigid rotors, shall be balanced in accordance with the requirements of paragraph 5.2.3.1.

NOTE: The pitch of each propeller blade should be the same. If this is not the case, the added mass on the propeller blades will be different, and the propeller will be unbalanced.

Table 528.1-IV. Types of balancing.

Rotor Characteristics	Speed (rpm)	Type of Balancing	Balancing Methods and Limits
Rigid, L/D [1/] ≤0.5	0 – 1000	Single-plane	5.2.2
	>1000	Two-plane	5.2.2
Rigid, L/D>0.5	0 – 150	Single-plane	5.2.2
	>150	Two-plane	5.2.2
Flexible	All	Multi-plane (more than two planes)	5.2.3

[1/] L – Length of rotor, exclusive of shaft.
D – Diameter of rotor, exclusive of shaft.

5.2.2 Balance Procedure for Rigid Rotors.

5.2.2.1 Balancing Methods for Rigid Rotors.

Except for machinery operating below 150 rpm, all balancing shall be accomplished by means of balancing equipment requiring rotation of the work piece. This may be either shop or assembly balancing type equipment. The minimum detectable unbalance of the balancing machine used shall be below the residual unbalance specified in paragraph 2.2.2. Unless otherwise specified, see Annex B paragraph 2g(2)), for machinery rated at lower than 150 rpm, the rotor including shaft may be balanced by symmetrically supporting the rotor on two knife edges, and applying correction to attain a static balance.

5.2.2.2 Balance Limits for Rigid Rotors.

When balanced as specified in paragraph 5.2.2.1, the maximum allowable residual unbalance is given by the following formula:

Given: $U = We \quad and \quad G = \omega e = 2\pi fe$

Where: U is the maximum allowable residual unbalance

G is the total balance quality grade (mm/sec) as specified (see Annex B, paragraph 2g(3))

W is weight of the rotor (lbs)

N is the maximum rotor rpm

e is the eccentricity limit (mm)

It can be shown that:

$$U = \frac{60GW}{2\pi N}\left(lbs \cdot mm\right)$$

or

$$U \cong \frac{6GW}{N}\left(oz \cdot in\right)$$

For rigid rotors that operate below 1000 rpm, the total balance quality grade shall not exceed G=2.5 mm/s. For rigid rotors that operate at 1000 rpm and above, the total balance quality grade shall not exceed G=1.0 mm/s. For rigid rotors that require low noise, a balance quality grade of G=1.0 mm/s can be specified for all speeds (see Annex B, paragraph 2g(3)). For guidance on balance quality grades of rigid rotors, see ANSI S2.19.

In allocating an allowable unbalance (U) between two planes of correction, the allocation ratio must not be more than 2 to 1. The amount allocated to each plane must be proportional to the distance from the other plane to the center of gravity (cg) of the rotor divided by the total distance between planes. If the distance between the correction planes is 25.4cm (10 inches), and the cg is 10cm (4 inches) from plane 1, plane 1 would be allowed 60 percent of U, and plane 2 would be allowed 40 percent. If the cg was 5cm (2 inches) from plane 1, plane 1 would be allowed 67 percent of U (not 80 percent), and plane 2 would be allowed 33 percent (not 20 percent), because the allocation ratio cannot be more than 2 to 1.

When specified (see Annex B paragraph 2g(4)), the residual unbalance for equipment with rigid rotors shall not result in vibration displacements larger than specified in Figure 528.1-2, when tested as in paragraph 5.2.3.2.

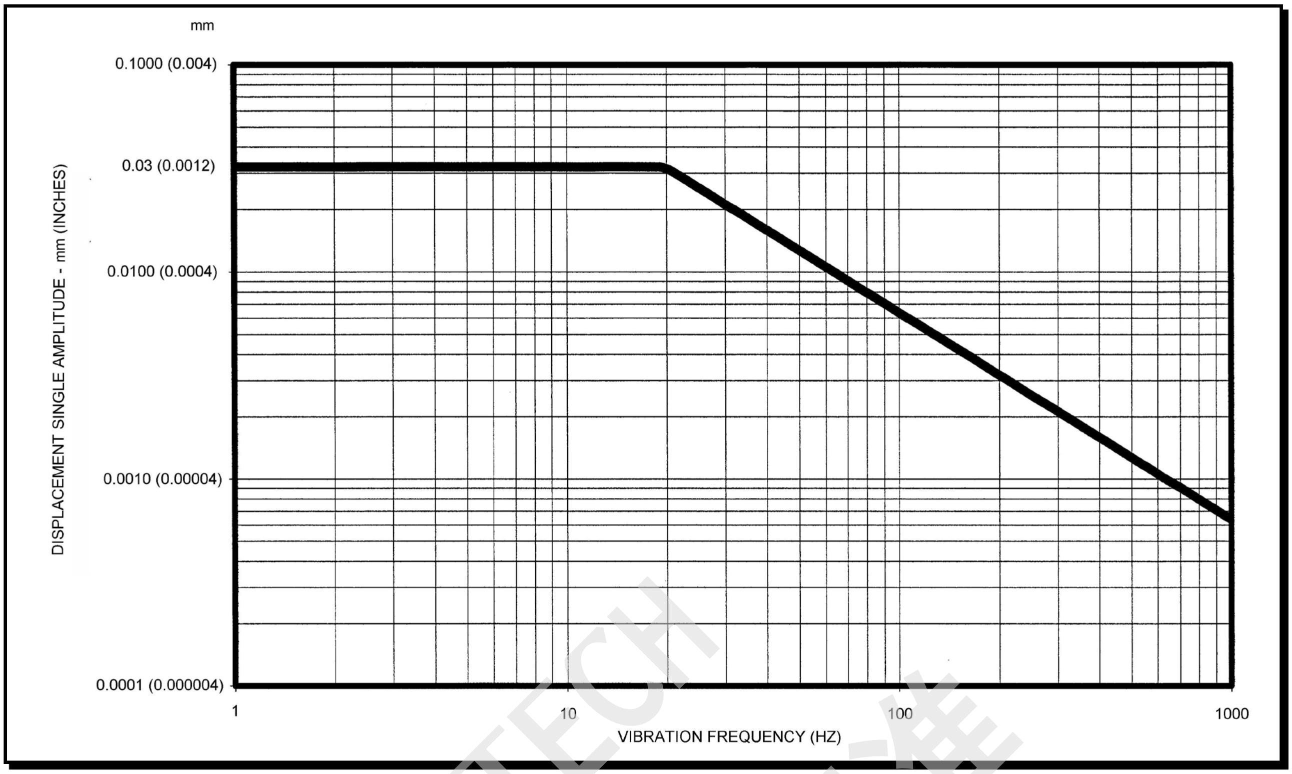

Figure 528.1-2. Vibration acceptance criteria for Type II vibration.

5.2.3 Balance Procedure for Flexible Rotors.

5.2.3.1 Balance Limits for Flexible Rotors.

The residual unbalance for flexible rotors shall not result in vibration displacements larger than specified in Figure 528.1-2 when tested as specified in paragraph 5.2.3.2.

5.2.3.2 Vibration Test Procedure.

When mounted as in paragraph 5.2.3.2.1 and measured in accordance with paragraph 5.2.3.2.2, the vibration displacement amplitude at the rotational frequency shall not exceed the values shown on Figure 528.1-2.

5.2.3.2.1 Mounting.

The test item shall be completely assembled and mounted elastically at a natural frequency corresponding to less than one-quarter of the frequency associated with the minimal operational speed of the equipment. To accomplish this, the minimum static deflection of the mounting should be determined by Figure 528.1-3, but in no case shall the deflection exceed one-half the original height of the elastic element. On machinery that cannot be mounted as described, the test item shall be mounted on the shipboard mounting for which it is intended, as specified (see Annex B, paragraph 2g(5)).

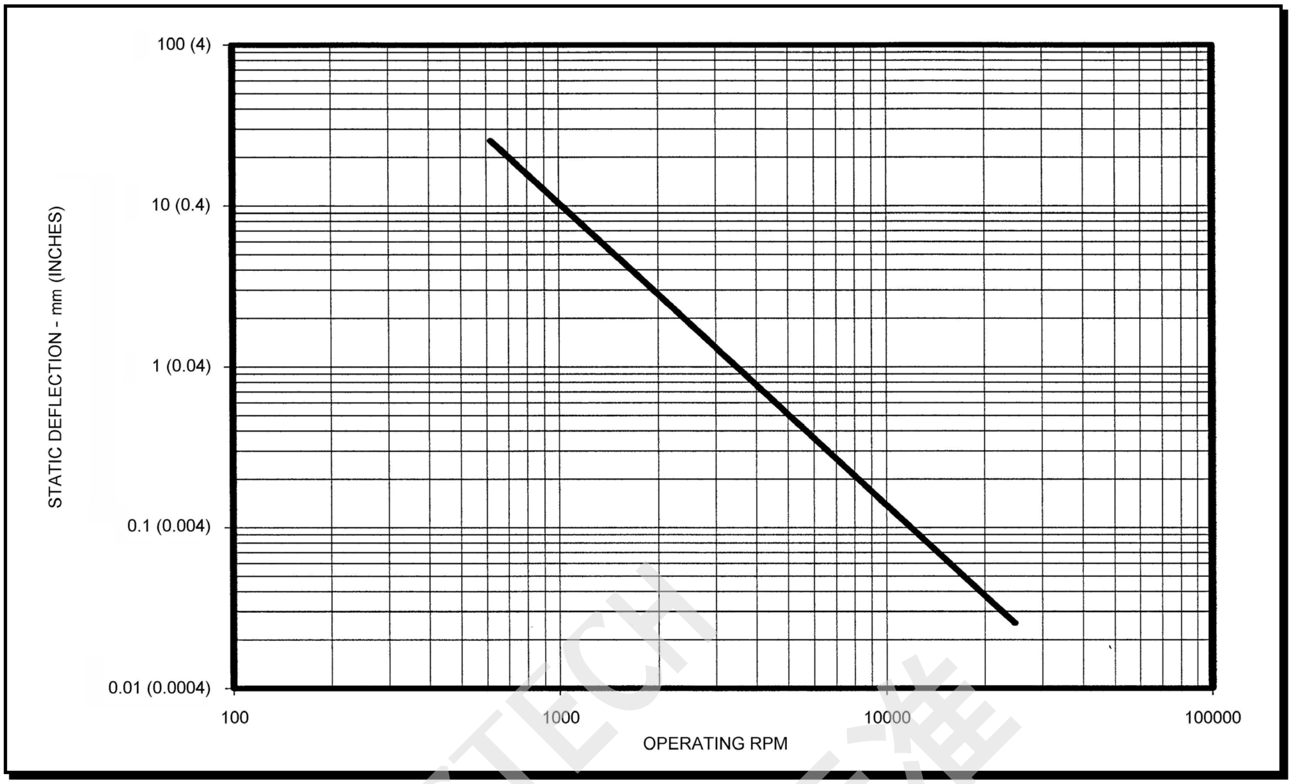

Figure 528.1-3. Minimum static deflection of mounting for Type II vibration test.

5.2.3.2.2 Measurements.

Amplitudes of vibration shall be measured on the bearing housing in the direction of maximum amplitude. On constant speed units, measurements shall be made at the operating speed. In the case of variable speed units, measurements shall be made at maximum speed, and at all critical speeds (see paragraph 2.2h) within the operating range. Measurements at many speeds may be required to establish the existence of critical speeds of variable speed units. The maximum frequency step size used when establishing critical speeds shall be 0.25 Hz.

5.2.3.2.3 Instruments.

Amplitude and frequency measurements shall be performed with instrumentation that has calibration traceable to the National Institute of Standards and Technology (NIST), and that has dynamic and frequency ranges consistent with the amplitude and frequency range specified in Figure 528.1-2.

5.3 Analysis of Results.

In addition to the guidance provided in Part One, paragraph 5.14, the following is provided to assist in the evaluation of the test results.

5.3.1 Physics of Failure.

Analyses of vibration related failures must relate the failure mechanism to the dynamics of the failed item and to the dynamic environment. It is insufficient to determine that something broke due to high cycle fatigue or wear. It is necessary to relate the failure to the dynamic response of the equipment to the dynamic environment. Thus, include in failure analyses a determination of resonant mode shapes, frequencies, damping values and dynamic strain distributions, in addition to the usual equipment properties, crack initiation locations, etc. (See Method 514.8, Annex A, paragraph 2.5, as well as paragraph 6.1, references k and l).

5.3.2 Qualification Tests.

When a test is intended to show formal compliance with contract requirements, recommend the following definitions:

a. Failure definition. "Equipment is deemed to have failed if it suffers permanent deformation or fracture; if any fixed part or assembly loosens; if any moving or movable part of an assembly becomes free or sluggish in operation; if any movable part or control shifts in setting, position or adjustment, and if test item performance does not meet specification requirements while exposed to functional levels and following endurance tests." Crack initiation in a critical structure constitutes failure of the test. Ensure this statement is accompanied by references to appropriate specifications, drawings, and inspection methods.

b. Test completion. "A vibration qualification test is complete when all elements of the test item have successfully passed a complete test. When a failure occurs, stop the test, analyze the failure and repair the test item. Continue the test until all fixes have been exposed to a complete test. Each individual element is considered qualified when it has successfully passed a complete test. Elements that fail during extended tests are not considered failures, and can be repaired to allow test completion." After testing, check all points of pre-identified stress concentration with a penetrating dye. This dye test will identify areas of crack initiation.

5.3.3 Other Tests.

For tests other than qualification tests, prepare success and/or failure criteria and test completion criteria that reflect the purpose of the tests.

6. REFERENCE/RELATED DOCUMENTS.

6.1 Referenced Documents.

a. MIL-M-17191 Mounts, Resilient: Portsmouth Bonded Spool Type (1970)

b. MIL-M-17508 Mounts, Resilient: Types 6E100, 6E150, 7E450, 6E900, 6E2000, 5E3500, 6E100BB, 6E150BB, 7E450BB, and 6E900BB

c. MIL-M-24476 Mounts, Resilient: Pipe Support, Types 7M50, 6M150, 6M450, 6M900, and 5M3500

d. MIL-M-19379 Mounts, Resilient, Mare Island Types 11M15, 11M25, and 10M50 (1961)

e. MIL-M-19863 Mount, Resilient: Type 5B5, 000H

f. MIL-M-21649 Mount, Resilient, Type 5M10, 000-H

g. MIL-STD-167-1A Mechanical Vibrations of Shipboard Equipment (Type 1 – Environmental and Type II – Internally Excited)

h. MIL-STD-167-2A Mechanical Vibrations of Shipboard Equipment (Reciprocating Machinery and Propulsion System and Shafting) Types III, IV, and V (Controlled Distribution)

i. MIL-STD-740-2 Structureborne Vibratory Acceleration Measurements Acceptance Criteria of Shipboard Equipment

j. Handbook for Dynamic Data Acquisition and Analysis, IEST-RD-DTE012.2; Institute of Environmental Sciences and Technology, Arlington Place One, 2340 S. Arlington Heights Road, Suite 100, Arlington Heights, IL 60005-4516; Institute of Environmental Sciences and Technology Website.

k. NATO STANAG 4570, Evaluating the Ability of Equipment to Meet Extended Life Requirements; 2004; Information Handling Services Website.

l. NATO Allied Environmental Engineering and Test Publication (AECTP) 600, "A Ten Step Method for Evaluating the Ability of Equipment to Meet Extended Life Requirements"; December 2004; Leaflet 604; NATO Website.

(Copies of these documents are available online at https://assist.dla.mil.

6.2 Related Documents.

See Annex B, Table 528.1B-I.

Egbert, Herbert W. "The History and Rationale of MIL-STD-810 (Edition 2)", December 2009; Institute of Environmental Sciences and Technology, Arlington Place One, 2340 S. Arlington Heights Road, Suite 100, Arlington Heights, IL 60005-4516.

(Copies of Department of Defense Specifications, Standards, and Handbooks, and International Standardization Agreements are available online at https://assist.dla.mil.

Requests for other defense-related technical publications may be directed to the Defense Technical Information Center (DTIC), ATTN: DTIC-BR, Suite 0944, 8725 John J. Kingman Road, Fort Belvoir VA 22060-6218, 1-800-225-3842 (Assistance--selection 3, option 2), http://www.dtic.mil/dtic/; and the National Technical Information Service (NTIS), Springfield VA 22161, 1-800-553-NTIS (6847), http://www.ntis.gov/.

(This page is intentionally blank.)

METHOD 528.1, ANNEX A

IDENTIFYING RESPONSE PROMINENCES TO BE INCLUDED IN ENDURANCE TESTING

1. SCOPE.

This Annex details the procedures for identifying response prominences to be included in endurance testing. This Annex is not a mandatory part of this Method. The following information is intended for guidance only.

2. PROCEDURE.

2.1 Determining and Displaying Transmissibility.

Present transmissibility information using the output responses and prescribed inputs. Use the transmissibility magnitudes for both exploratory and variable frequency tests for response prominence determinations.

2.1.1 Transmissibility Magnitudes.

Develop transmissibility magnitudes by dividing the measured output amplitudes by the input amplitudes using consistent units (e.g., acceleration in gs or inches/sec^2).

2.1.2 Transmissibility and Frequency.

Present transmissibility information in linear-linear format. Plots or tabulations are acceptable. Present both the transmissibility and frequency information in linear units (i.e., do not use logarithms or dB of either frequency or transmissibility to compute or display the data used for response prominence determinations).

2.2 Identifying Response Prominences.

Regardless of whether or not the transmissibility exceeds 1.0, find all local maxima in the transmissibility magnitude-frequency data and include the frequency endpoints in the list of maxima.

a. For each of these maxima, determine if there is reason to believe that the maximum is attributable to an instrumentation error, a fixture resonance or from a numerical error related to computation of the transmissibility (round-off errors may appear as maxima). Any maxima that are attributable to an instrumentation error, fixture resonance, or numerical errors must be discarded as a potential response prominence. Fixture resonances are not permitted, and refixturing must be employed to eliminate such resonances.

b. Examine the end points for indications that a resonance may exist outside the test frequency range.

c. An initial decrease in transmissibility with increasing frequency above the frequency of the lower end point suggests a potential response prominence outside the lower bound of the test frequency range. If this condition is observed and is not attributed to shaker problems at low frequencies, include the lower endpoint in the candidate list of endurance test frequencies noting whether or not it affects functional or structural integrity. If this condition is not observed, the lower bound test frequency may be discarded as a potential response prominence. At these low frequencies, noticeable displacement magnitude amplifications may occur if a true response prominence exists below the lower frequency bound of testing and this fact may be used to help determine the nearby presence of a true response prominence.

d. Similarly, an increase in transmissibility with increasing frequency near the upper bound test frequency suggests a potential response prominence outside the upper bound of the test frequency range. If this condition is observed, include the upper endpoint in the candidate list of endurance test frequencies noting whether or not it affects functional or structural integrity. If it is not observed, this frequency cannot be excluded from the list of endurance test frequencies unless other response prominence frequencies are found.

e. Observe whether or not equipment function (if permitted by the ordering data) or structural integrity is affected at any of the frequencies used in exploratory or variable frequency testing. Include those frequencies at which equipment functional or structural integrity is affected in the candidate list of endurance test frequencies. Also include frequencies at which maxima occur in the candidate list of endurance test frequencies if the impact on functional/structural performance cannot be established.

f. Examine the remaining maxima for classic signs of resonance (i.e., a moderate to rapid increase in transmissibility to the peak followed by a moderate to rapid decrease in the transmissibility with increasing frequency after the peak suggests that a response prominence may exist in this region) and include any maxima that exhibit these characteristics in the candidate list of endurance test frequencies.

2.3 Selecting Endurance Test Frequencies.

2.3.1 Non-responsive Prominence Frequencies Where Functional or Structural Integrity Is Affected.

Include in the list of endurance test frequencies, any frequency at which a structural, functional, mechanical, or electrical anomaly has occurred (if permitted by the acceptance criteria (see paragraph 5.1.1 at the beginning of this Method, as well as Annex B, paragraph 2f(1)). Examples of these manifestations could be unexpected switch closures, unexpected changes in pressure or flow, variations in voltage, current, etc. The frequencies where any minor impairment of function occurs that does not warrant interruption of testing to develop a fix must also be included in the list of endurance test frequencies.

2.3.2 Frequencies Where Response Prominences Have Been Identified.

Components may contain many parts and subassemblies that can resonate. Some components may have nonlinear characteristics such as clearances between parts or equipment mounted on isolation mounts. Therefore, the amplitude of excitation may be important relative to identifying response prominences for these components. Input amplitude dependent response prominences may potentially be the same overall resonance rather than different ones. In light of this potential, unusual test results, such as uncovering response prominences during variable frequency testing that were not uncovered during exploratory testing, need to be thoroughly investigated to not only try and determine the cause of the response prominence but to ascertain whether the response prominence is unique or part of another response prominence. Criteria for selecting response prominences for endurance testing are as follows:

a. A transmissibility greater than 1.5 at any measurement location is sufficient to classify a maximum as a response prominence, and include the corresponding frequency in the list of endurance test frequencies. However, the converse is not necessarily true, i.e., a response prominence whose transmissibility is less than 1.5 cannot be excluded solely on the magnitude of the transmissibility. Possible explanations as to why transmissibility maxima of magnitudes less than 1.5 may still represent real response prominences are:

    (1) The transducer may not be at the point of maximum response. If probing or some other means cannot be employed to locate the point of maximum response (e.g., due to inaccessibility), then all maxima displaying the classic characteristics of a resonance that cannot be attributed to instrumentation or numerical error must be identified as response prominences, and their frequencies included in the list of endurance test frequencies.

    (2) The transducer may be at or near a response node point (location of minimal or low response in a vibration mode) at that frequency. The location of node points (as well as the locations of maximum response) can change location as changes in the drive frequency excite different modes of vibration.

    (3) The mass of the part and the amplitude of vibration of the mass that is in maximum response are not large enough to generate the forces necessary to cause structural responses of large enough magnitude at the location of the transducer.

    (4) The driving frequency is not exactly at the resonant frequency, thus the peak response is not obtained.

b. Without further investigation, the existence of a response prominence for the remaining maxima cannot be confirmed, nor the possibility of the existence of a response prominence excluded. If practical, an attempt should be made to obtain further information to resolve this issue by probing for the maximum response location with movable transducers, listening, visually locating or feeling for the maximum response points.

c. If it can be shown that response prominences uncovered do not compromise equipment structural/functional integrity, these response prominences do not have to be included in the endurance test. Justification should be provided in the test report as to why these response prominences have been excluded from endurance testing.

2.4 Guidance for Specifiers.

Carefully determine all functions of the equipment that must be preserved under normal shipboard vibration. Determine the functional requirements that must be met during the vibration tests including the appropriate test acceptance criteria and include them in the procurement documents. A careful and thorough evaluation of the functional requirements will significantly reduce the potential for problems, define the basis for instrumentation selection and placement, and help in the interpretation of test results.

If possible, determine how and where to instrument the test item based on the functional requirements and expected responses, or consider requiring the vendor to make this determination. If an area of concern cannot be directly instrumented, consider instrumenting to find alternate manifestations of this area of concern (e.g., voltage fluctuations, pressure variations, noise, and contact closures). While analyses of the test and test equipment (if performed) can provide insights into possible test responses of some equipment, often neither extensive nor complicated analyses are needed, and common sense alone can often be used to establish reasonable locations of instrumentation if the functional requirements are well known. If the test vendor will determine the instrumentation scheme, depending on the equipment, consider requesting the instrumentation scheme for information or approval.

Depending on the equipment, consider requiring prior approval of frequencies used for endurance testing.

(This page is intentionally blank.)

METHOD 528.1, ANNEX B

NOTES AND ENGINEERING GUIDANCE

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

1. INTENDED USE.

a. This Method is used to qualify shipboard equipment for the environmental vibrations and internally excited vibrations encountered during operation of the equipment aboard ship.

b. In some special machinery, equipment, or installations (such as antennae, large machinery items, and certain unique designs), it may be necessary to deviate from this Method.

c. Type I vibration testing is intended to qualify new equipment for exposure to shipboard vibrations during the lifetime of the ship (approximately 30 years).

d. The primary purpose of Type I vibration testing is to prove the physical and functional integrity of equipment when subject to a prescribed steady-state vibration environment. The results of the application of this Method do not provide a definitive determination of the test item's natural frequencies and mode shapes.

e. This Method does not cover vibrations associated with reciprocating machinery, or those associated with propulsion and shafting. For these types, see MIL-STD-167-2A.

f. The primary purpose of the application of this Method to Type II vibrations is from the standpoint of mechanical suitability, and not from a structure-borne noise standpoint. See MIL-STD-740-2 for noise suitability of equipment.

2. ACQUISITION REQUIREMENTS.

Acquisition documents should specify the following:

a. Title, number, and date of the method.

b. Reporting requirements, including requirements for Notification of Test, Equipment Test Plan, and/or Test Report (see paragraphs 4.1, 5.1.2.5.1, and 5.1.2.5.2 in the front part of this Method).

c. Identification of component compliance on component drawing, in Test Report, or on label plate (see paragraph 4.2).

d. Disposition of tested equipment and related equipment (see paragraph 4.3 in the front part of this Method).

e. Type(s) of vibration required (see paragraphs 5.1 and 5.2 in the front part of this Method).

f. Type I:

(1) How the equipment will be operated after the test to demonstrate the machinery or equipment has no damage from the test, including acceptable operational degradations (see paragraphs 5.1.1 and 5.1.2.4.1 in the front part of this Method).

(2) Whether the test engineer needs concurrence of the procuring agency for determination of major vs. minor failures before continuing testing (see paragraph 5.1.1 in the front part of this Method).

(3) Whether measurement transducer locations need to be approved by the procuring agency for Type I testing (see paragraph 5.1.2.2) in the front part of this Method).

(4) Methods of mounting equipment for test (see paragraph 5.1.2.3.4 in the front part of this Method).

(5) Whether internal mounts should be installed for all, a specific part, or none of the test (see paragraph 5.1.2.3.5 in the front part of this Method).

(6) How the test item will be energized or operated during Type I vibration tests (e.g., pressure, flow rate, voltage current, and cycling of principal functions during testing), including acceptable operational degradations (see paragraphs 5.1.1 and 5.1.2.4.1 in the front part of this Method).

(7) When required, the maximum test frequencies (see paragraph 5.1.2.4.4 in the front part of this Method)

(8) Alternative test amplitudes (see paragraph 5.1.2.4.5 in the front part of this Method).

(9) Whether approval is required for selection of frequencies used for endurance testing (see paragraphs 5.1.2.4.6 and 5.1.2.4.7 in the front part of this Method).

(10) The acceptance authority for the test report and any other approval items (see paragraphs 5.1.2.5.1 and 5.1.2.5.2 in the front part of this Method).

g. Type II:

(1) Special vibration and balance requirements (see paragraph 5.2 in the front part of this Method).

(2) Whether dynamic balance is required for machinery rated at lower than 150 rpm (see paragraph 5.2.2.1 in the front part of this Method).

(3) Balance quality grade (see paragraph 5.2.2.2 in the front part of this Method).

(4) Whether vibration acceptance criteria of Figure 528.1B-2 are specified for equipment with rigid rotors (see paragraph 5.2.2.2 in the front part of this Method).

(5) When required, methods of mounting test items for test (see paragraph 5.2.3.2.1 in the front part of this Method).

3. ASSOCIATED DATA ITEM DESCRITIONS (DIDs).

This Method has been assigned an Acquisition Management Systems Control (AMSC) number authorizing it as the source document for the following DIDs. When it is necessary to obtain the data, the applicable DIDs must be listed on the Contract Data Requirements List (DD Form 1423).

DID Number	DID Title
DI-ENVR-81647	Mechanical Vibrations of Shipboard Equipment Measurement Test Plan and Report
DI-MISC-81624	Notification of Test/Trials

4. TAILORING GUIDANCE FOR CONTRACTUAL APPLICATION.

Note: Equipment installed aboard Naval ships is subjected to varying frequencies and amplitudes of environmental vibration for extended periods of time, during which they are required to perform their normal function. Principal causes of steady state shipboard vibration are propeller blade excitation and unbalanced forces of the propeller and shafting. Vibrations are also experienced by shipboard mounted equipment caused by mounting system resonances, changes in ship speed and heading, and changes in sea state. Vibration magnitudes measured on a ship during vibration trials should not be compared with the magnitudes shown in Table 528.1-I because ship vibration trials are conducted in quiet water to achieve repeatable results during which changes in speed and heading are not made. See ANSI S2.25 for additional tailoring guidance.

a. The frequency range for Type I vibrations is determined based on blade rate frequencies associated with a specific ship design. If equipment is to be tested for use on multiple ship classes, the equipment may be tested over the frequency range encompassing various ship classes as required.

b. For Type I testing, if equipment is to be tested for use on multiple ship classes, the choice of equipment mounting may affect the number of tests required to qualify the equipment for use on the intended ships.

5. SUPERSEDING DATA.

This Method covers Types I and II vibration requirements formerly covered in MIL-STD-167-1 & 1A (SHIPS). Types III, IV, and V requirements are covered in MIL-STD-167-2A (SH).

6. GUIDANCE DOCUMENTS.

Table 528.1B-I lists documents that provide design guidance and definitions in the field of vibration.

Table 528.1B-I. Related documents.

AMERICAN NATIONAL STANDARDS INSTITUTE (ANSI)		
S1.1	-	Acoustical Terminology
S2.4	-	1990, American Standard Methods for the Specifying of Characteristics of Auxiliary Analog Equipment for Shock and Vibration
S2.5	-	1990, American Standard Methods for Specifying the Performance of Vibration Machines
S2.7	-	1990, American Standard Terminology for Balancing Rotating Machinery
S2.19	-	Mechanical Vibration – Balance Quality Requirements of Rigid Rotors, Part 1: Determination of Permissible Residual Unbalance, Including Marine Applications
S2.25	-	Guide for the Measurement, Reporting, and Evaluation, of Hull and Superstructure Vibration in Ships
INTERNATIONAL STANDARDS ORGANIZATION (ISO)		
1940/1	-	1986, Mechanical Vibration – Balance Quality Requirements of Rigid Rotors – Part 1: Determination of Permissible Residual Unbalance
DEPARTMENT OF DEFENSE		
SPECIFICATIONS		
MIL-M-17185	-	Mounts, Resilient; General Specifications and Tests for (Shipboard Application)
STANDARDS		
MIL-STD-740-2	-	Structureborne Noise Measurements and Acceptance Criteria of Shipboard Equipment
NAVAL SEA SYSTEMS COMMAND (NAVSEA) PUBLICATIONS		
NAVSHIPS 94323	-	Maintainability Design Criteria Handbook for Design of Shipboard Electronic Equipment
NAVSHIPS 0967-316-8010	-	BUSHIPS Reliability Design Handbook (Electronics)
NAVSHIPS 0967-309-3010	-	Design of Shock and Vibration Resistant Electronic Equipment for Shipboard Use
NAVSEA 0900-LP-090-3010	-	Guideline to Military Standard MIL-STD-167-1 (SHIPS) Mechanical Vibrations of Shipboard Equipment, December 1993
SVM-18	-	Shock and Vibration Design Manual, Naval Sea Systems Command, April 2001

(This page is intentionally blank.)