

Reaffirmed by ANSI
July 12, 2007

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June 24, 2014

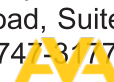
ANSI S2.27-2002

AMERICAN NATIONAL STANDARD **GUIDELINES FOR THE MEASUREMENT AND EVALUATION OF VIBRATION OF SHIP PROPULSION MACHINERY**

ANSI S2.27-2002

Accredited Standards Committee S2, Mechanical Vibration and Shock

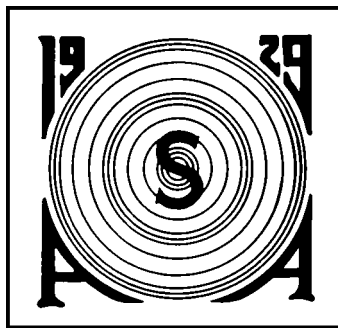
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AMERICAN NATIONAL STANDARD

**Guidelines for
the Measurement and Evaluation
of Vibration of Ship Propulsion
Machinery**

Secretariat
Acoustical Society of America

Approved 20 September 2002
American National Standards Institute, Inc.

Abstract

This standard contains guidelines for the measurement and evaluation of vibration of ship propulsion systems including limits for acceptability. It is applicable to all ocean-going ships and inland vessels. Test conditions, instrumentation, data analysis and evaluation, and reporting requirements are described.

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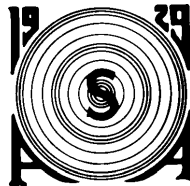
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Contents

	Page
Foreword	iii
0 Introduction	1
1 Scope, purpose and applications	1
2 References	1
2.1 Normative references	1
2.2 Informative references	1
3 Definitions	2
4 Calculations	2
4.1 Torsional vibration calculations	2
4.2 Lateral vibration calculations	3
4.3 Longitudinal vibration calculations	3
4.4 Calculations for diesel engines	4
4.5 Calculations for thrusters, cycloidal propellers and waterjets	4
4.6 Calculations for gearboxes	4
5 Vibration tests	4
5.1 Instrumentation	4
5.2 Test conditions	5
5.3 Test procedure	5
5.4 Data processing	6
5.5 Measurements	6
6 Acceptance criteria	8
6.1 Torsional vibration	8
6.2 Lateral vibration	8
6.3 Longitudinal vibration (conventional systems)	9
6.4 Vibration of diesel engines	9
6.5 Vibration of thrusters	9
6.6 Vibrations of cycloidal propellers and waterjets	9
6.7 Gearboxes	9
7 Report	10
Annexes	
A Optional test procedures and calculation requirements	13
A1 General	13
A2 Test procedure	13
A3 Calculations	13
A4 Criteria	13
B Torsional shaft stress criteria	14
B1 General	14
C Example calculations of vibration properties of ship propulsion systems	16
C1 Torsional calculations	16
C2 Longitudinal calculations	17
C3 Lateral vibration	21
D Bibliography	23

	Page
Tables	
1 Summary of acceptance criteria	11
2 Particulars of test ship	12
C1 Description of elements	18
Figures	
B1 Stress concentration factor at keyway	15
B2 Stress concentration factor for shaft flange fillet in torsion	15
C1 Equivalent systems for calculating torsional natural frequencies of a geared turbine-driven propulsion system	16
C2 Calculated mode shapes for geared-turbine drive	17
C3 Propulsion shafting details	18
C4 Propulsion system longitudinal vibration model	19
C5 Calculated propulsion system longitudinal natural frequencies vs. machinery foundation stiffness for a 4-bladed propeller	19
C6 Calculated propulsion system longitudinal blade rate vibration response for a 4-bladed propeller (machinery fdn stiffness = 5×10^6 lb/in; total thrust brg stiffness = 3×10^6 lb/in) ..	20
C7 Propulsion shafting first mode whirling frequency vs. propeller bearing and aft stern tube bearing stiffnesses	21
C8 Simplified (Jasper) model of propulsion shafting lateral vibration	22

Foreword

[This Foreword is for information only, and is not a part of the American National Standard ANSI S2.27 - 2002– Guidelines for the Measurement and Evaluation of Vibration of Ship Propulsion Machinery].

This standard comprises a part of a group of definitions, standards, and specifications for use in mechanical vibration and shock. It has been developed using the American National Standards Institute (ANSI) Accredited Standards Committee Procedure. The Acoustical Society of America provides the Secretariat for Accredited Standards Committee S2, Mechanical Vibration and Shock.

American National Standards Committee S2, Mechanical Vibration and Shock, under whose jurisdiction this standard was developed, has the following scope:

Standards, specifications, methods of measurement and test terminology in the fields of mechanical vibration and shock and condition monitoring and diagnostics of machines, but excluding those aspects which pertain to biological safety, tolerance, and comfort.

This standard is comparable to parts of ISO 4867:1984, Code for the measurement and reporting of shipboard vibration data.

At the time this Standard was submitted to Accredited Standards Committee S2, Mechanical Vibration and Shock for approval, the membership was as follows:

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Working Group S2/WG11, Measurement and Evaluation of Mechanical Vibration of Vehicles, which assisted Accredited Standards Committee S2, Mechanical Vibration and Shock, in the development of this standard, had the following membership:

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Suggestions for the improvement of this standard are welcomed. They should be made in writing to Accredited Standards Committee S2, Mechanical Vibration and Shock, in care of the Standards Secretariat, Acoustical Society of America, 35 Pinelawn Road, Suite 114E, Melville, New York 11747. Telephone: +1 631 390 0215; FAX: +1 631 390 0217; e-mail: asastds@aip.org.

American National Standard

Guidelines for the Measurement and Evaluation of Vibration of Ship Propulsion Machinery

0 Introduction

This national standard provides guidelines for acceptable vibration of new marine propulsion machinery during normal operation of the ship. This standard also defines requisite calculations and the measurement and data processing procedures to obtain reliable data to compare with the guidelines.

In addition to addressing the more common types of propulsion systems, such as geared-turbine and diesel drive, this standard includes thrusters, cycloidal propellers and waterjets.

The design of a ship propulsion system is a continuing process of analysis and testing, during which components are analytically evaluated with increasing complexity as the details of the design evolve. This process culminates with ship testing. Eventual proof of performance is demonstrated in full-scale ship trials with the installed propulsion system. This national standard provides guidance for evaluating the vibration of a propulsion system during the design cycle and a detailed description of the vibration tests to be conducted during ship trials.

These guidelines treat longitudinal, lateral and torsional vibration of conventional systems and, as applicable, non-conventional systems. While vibration tests are the basis of acceptability, calculations are usually required in addition to measurements to indicate probable compliance with acceptance criteria. The requirements for calculations are given in paragraph 4; test procedures, instrumentation and data analysis are described in paragraph 5; and the acceptance criteria are contained in paragraph 6.

Evaluation of a ship's vibration environment for habitability is dealt with in ANSI S2.25 [2].

1 Scope, purpose and applications

This standard establishes uniform procedures for determining the acceptance of new marine propulsion machinery with respect to vibration of sea-going and inland ships of all lengths, excluding ice-breakers.

NOTE – This standard covers vibrations of ships in steady underway conditions but does not include the vibrations resulting from special operations such as the crushing of ice by an icebreaker.

This standard covers propulsion systems with turbine (both gas and steam), electric and diesel drives with single or multiple shafts, thrusters, and cycloidal propeller and waterjet systems. Propulsion systems have higher vibration magnitudes than most other shipboard machinery because of propeller excitation. There are some special requirements, such as avoiding thrust reversals in the thrust bearing and torque reversals in the gear trains. Table 1 presents a summary of acceptance criteria.

Although this standard is intended for new ships, it can also be used during the life of the ship to check for mechanical damage, performance monitoring and evaluating a repair, provided, however, that some allowances are made for wear, erosion of parts, etc.

2 References

2.1 Normative references

[1] ISO 2041:1990, Mechanical vibration and shock—Vocabulary.

2.2 Informative references

[2] ANSI S2.25:2001, American National Standard Guide for the Measurement, Reporting, and Evaluation of Hull and Superstructure Vibration in Ships.

[3] General Radio, *Handbook of Noise Measurement*, General Radio, Seventh Edition, General Radio Company, Concord, MA, USA, 1974 (out of print).

[4] ISO 10816-6:1995, Mechanical vibration—Evaluation of machine vibration by measurements on non-rotating parts—Part 6: Reciprocating machines with power ratings above 100 kw.

[5] ANSI/AGMA 6000-B96:1996, Specification for Measurement of Linear Vibration on Gear Units.

[6] ISO 8579-2, Acceptance code for gears Part 2: Determination of mechanical vibrations of gear units during acceptance testing.

[7] Society of Naval Architects and Marine Engineers, "Principals of Naval Architecture," New York, New York, 1957.

3 Definitions

This section defines only some of the terms used in this standard. See ISO 2041 [1] for definitions of a general nature.

3.1 amplitude spectrum. A plot of magnitudes versus frequency occurring in a dynamic signal.

3.2 broadband. Having frequency components distributed over a wide frequency band, usually one octave or greater.

3.3 Cardan shaft. A shaft with Hooke's universal joints at both ends.

3.4. conventional propulsion system. A system in which propellers are driven by a geared or direct drive, where all the machinery is inboard, except for the shafting, which also penetrates the hull and supports an external propeller.

3.5 crest factor. The ratio of the peak signal value to the rms value of the signal.

NOTE – The value of the crest factor of a sine wave is the square root of 2.

3.6 critical frequency. A natural frequency of a mechanical system, associated usually with a lower-order mode, which can be excited by an external or internal force such as shaft rpm or blade frequency. In general, excitation of such modes is to be avoided.

3.7 free route. That condition achieved when the ship is proceeding at a constant speed with minimum rudder angles.

3.8 non-conventional propulsion systems. A class of propulsion systems which includes various types of thrusters (maneuvering or propulsion, fixed or variable direction, with ducted or open propellers, etc.), cycloidal propellers and waterjets.

3.9 peak value; peak magnitude. The maximum value of a raw signal during a given interval.

3.10 rms. The square root of the average of the squared values of a function over a given time interval.

3.11 vibration severity. A generic term that des-

ignates a value or set of values, such as a maximum value, average or rms value, or some other parameter that is descriptive of the magnitude of vibration.

3.12 wake survey. A method, generally on model scale, of measuring the velocity flow in the plane of the propeller of a ship's hull when towed in a straight-line course at constant speed (usually design speed).

NOTE – The wake survey, together with the model test (propulsion test) and application of a computer code, will enable one to compute the alternating propeller forces as a percentage of mean thrust.

4 Calculations

A complete mathematical analysis of the lateral and torsional vibration of the propulsion system shall be submitted to the purchaser before trials so that it can be determined if the test requirements are likely to be satisfied. Such information shall be provided far enough in advance of trials to allow sufficient time for redesign or modification. In conventional systems, longitudinal vibration calculations shall be made in accordance with paragraph 4.3.

NOTE – There are many programs and simulation techniques, which are used to model dynamic systems. The subject of modeling is far too complex to be dealt with in this National Standard. The user is referred to the bibliography in ANNEX D as a starting point if they are not already familiar with the modeling techniques. ANNEX C shows, by way of example, the modeling and calculated results of the low-frequency vibration of typical geared-turbine drive propulsion systems.

4.1 Torsional vibration calculations

The following tasks are to be included in the mathematical analysis of the torsional vibration to be supplied to the purchaser:

- Calculate the natural frequencies and modal patterns of all the important modes of vibration and for all the modes of operation (different drivers engaged, etc.).
- For each mode, calculate the relationship between the most highly stressed section of shafting and the stress or torsional vibration at the proposed measurement location.
- Estimate all the important vibratory magnitudes, vibratory stresses and vibratory torques

on the gears of the unit. Responses due to engine and propeller excitation shall be combined when estimating magnitudes. Response calculations shall be performed for the following operating speed ranges:

- For a constant speed unit, from 80% to 120% of design rpm. (For constant speed units that also have an idle speed (such as a diesel generator), the calculation shall include also that condition.)
 - For a variable speed unit, from 80% of the lowest normal operating speed to 115% of the design rpm.
- d) Rotational displacements across the couplings, and torques acting on the couplings.
- e) For diesel drives the quantities in c) and d) shall also be calculated for a single cylinder misfire. The ship specifications may also require that the same calculations be made for the worst case of two cylinders misfiring. These calculations shall be used to establish prohibited speed ranges where calculated stresses or torques exceed the limits in 6.1.

NOTE – As an example, if, in a direct-drive diesel system, an unacceptable critical frequency is calculated to occur in the operating range, there are two approaches [D1] to mitigate its effects: 1) Lower the critical frequency by decreasing the shaft diameter or adding a tuning wheel to the crankshaft. This will, however, require the introduction of a prohibited speed range, i.e., a speed range through which the shaft must pass as quickly as possible to reach the desired rpm. The limits of this range are on the order of 15% above and below the critical rpm; 2) install engine torsional damper to reduce the torsional vibratory stresses to tolerable levels. The first approach is recommended as the most practical and cost-effective procedure, if it can be implemented.

There are two multiplicative operational factors that shall be applied to the rms values of torque, as calculated from a wake survey, used as input to the torsional vibration calculations for conventional systems:

- a) The crest factor which usually has a value of about 4.
- b) The full power factor, which is applied to the upper 10% of the operating range to account for cavitation or other loading of the propeller

that occurs only at high speed. The value of this factor varies linearly from 1.0 at 90% of design rpm to an empirically derived value at design speed, usually about 1.5.

NOTE – If wake survey results are not available for a particular ship, estimates of alternating torque may be made from similar ships or from typical figures given in the literature. Care must be taken to ensure that these estimates are comparable to rms values as those calculated from a wake survey. For example, they may be expressed as a single amplitude rather than rms, or they may already take the modulation factor into account.

4.2 Lateral vibration calculations

The analysis of lateral vibration must usually demonstrate that the system is free from any predicted lateral critical frequencies below 115% of design rpm (230% for Cardan shafts). Some systems, such as those in high-performance ships, are designed with resonances that lie within the operating range, in which case response calculations shall be performed. If the system contains more than one section between flexible couplings, universal joints, gears, etc., similar calculations shall be made for each section unless there is no question that the lateral natural frequencies are sufficiently high. The mathematical analysis shall include the following:

- a) Natural frequencies and modal patterns of all important modes of vibration, accounting for, where applicable, the gyroscopic effect of the propeller.
- b) The calculation of the radial stiffnesses of the shaft bearings and associated support structures. If vertical and horizontal stiffnesses are significantly different, separate vertical and horizontal models shall be used.

4.3 Longitudinal vibration calculations

The primary objective of the longitudinal vibration calculations is to determine the possibility of excessive alternating thrust, particularly thrust reversals, during operation. Calculations shall be performed for each normal operating mode (such as various combinations of clutches engaged) and shall include the following:

- a) Using estimated values of propeller alternating thrust and damping, calculate the rms vibratory velocities of the mathematical model

for blade frequency excitation throughout the operating range and up to 115% of design rpm.

- b) Calculate the peak value of the blade frequency alternating thrust (as a percentage of the mean thrust) at the main thrust bearing throughout the operating range, including critical speeds, up to 115% of design rpm.
- c) Calculate the vibratory stresses on the reduction gear teeth due to longitudinal vibration throughout the operating range, as a percentage of the stresses caused by the normal steady torque at design speed.

The same crest factor and full-power factor described in paragraph 4.1 shall be applied to the rms values of thrust as calculated from wake surveys and used as input to the longitudinal vibration calculations.

4.4 Calculations for diesel engines

In addition to the torsional calculations required in paragraph 4.1, calculations are required to ensure that the natural frequencies of the engine on its foundation or mounts do not coincide with the major excitation frequencies. The following shall be included in such an analysis:

Calculate the translational and rocking frequencies and compare with the major excitation frequencies for that installation.

4.5 Calculations for thrusters, cycloidal propellers and waterjets

In addition to the torsional vibration calculations required in paragraphs 4.1, calculations are required to ensure that the natural frequencies of the thruster, cycloidal propeller unit or waterjet on its foundation or mounts do not coincide with the major excitation frequencies of the driver or propulsor (rotational and blade rate frequencies). If propulsion units similar in size, speed, and power, and on comparable foundations, have operated satisfactorily “for a year or more”, the purchaser may waive the calculations.

NOTE – In most cases, where a propulsor is mounted to the ship’s bottom, it can be assumed that the ship’s bottom restricts the rotational motion about the vertical axis and the horizontal motion of the unit, so that only the vertical and the two rocking frequencies need to be calculated.

Calculations of the natural frequencies of the propulsion unit on its mounts or foundation shall then be compared with the major excitation frequencies for that system.

4.6 Calculations for gearboxes

Calculations are required to ensure that the natural frequencies of the gearbox on its foundation or mounts do not coincide with major excitation frequencies, including those where bearing reactions result from alternating torques in gears. If gearboxes similar in size, speed and power, on comparable foundations, and with similar excitations have operated satisfactorily “for a year or more”, the purchaser may waive the calculations.

NOTE – In most cases, where a gearbox is mounted to the ship’s bottom, it can be assumed that the ship’s bottom restricts the rotational motion about the vertical axis and horizontal motion of the unit, so that only the vertical and two rocking frequencies need be calculated.

Calculations of the natural frequencies of the gearbox unit on its mounts or foundation shall then be compared with the major excitation frequencies for that system.

5 Vibration tests

Vibration tests are required to demonstrate the acceptability of new propulsion systems. This section describes the instrumentation, test conditions, test procedures and data processing requirements.

5.1 Instrumentation

Transducers suitable for acquiring acceleration or velocity data between 1 Hz and 1,000 Hz shall be used. If it is known that there are no major excitations at very low frequencies, a lower limit of greater than 1 Hz may be acceptable. Also, the upper limit may be reduced if there are no significant excitations at the higher frequencies. The builder and purchaser shall agree to any changes, such as the frequency range, before the test.

At the time of publication of this standard, most vibration transducers are designed to generate signals proportional to acceleration, and it is necessary to integrate the signal with respect to time to obtain a velocity record.

NOTE – Integrating at low frequencies (near 1 Hz) may introduce errors, and therefore requires caution for the measurement system at low frequencies.