



AMERICAN NATIONAL STANDARD

**Mechanical vibration — Rotor balancing —
Part 12: Procedures and tolerances for rotors with
flexible behaviour
(a nationally adopted international standard)**

Secretariat:

Acoustical Society of America

Approved on September 24, 2019:

American National Standards Institute, Inc.

Abstract

This nationally adopted international standard presents typical configurations of rotors with flexible behaviour in accordance with their characteristics and balancing requirements, describes balancing procedures, specifies methods of assessment of the final state of balance, and establishes guidelines for balance quality criteria. Can also serve as a basis for more involved investigations, e.g. when a more exact determination of the required balance quality is necessary. If due regard is paid to the specified methods of manufacture and balance tolerances, satisfactory running conditions can be expected. Is not intended to serve as an acceptance specification for any rotor, but rather to give indications of how to avoid gross deficiencies and unnecessarily restrictive requirements. Structural resonances and modifications thereof lie outside the scope of this document. The methods and criteria given are the result of experience with general industrial machinery. It is possible that they are not directly applicable to specialized equipment or to special circumstances. Therefore, in some cases, deviations from this document are possible.

AMERICAN NATIONAL STANDARD

Mechanical vibration — Rotor balancing — Part 12: Procedures and tolerances for rotors with flexible behaviour (a nationally adopted international standard)

ANSI/ASA S2.81-2019/Part 12/ ISO 21940-12:2016

Accredited Standards Committee S2, Mechanical Vibration and Shock

Standards Secretariat
Acoustical Society of America
1305 Walt Whitman Road
Melville, NY 11747

The American National Standards Institute, Inc. (ANSI) is the national coordinator of voluntary standards development and the clearinghouse in the U.S.A. for information on national and international standards.

The Acoustical Society of America (ASA) is an organization of scientists and engineers formed in 1929 to increase and diffuse the knowledge of acoustics and to promote its practical applications.



AMERICAN NATIONAL STANDARD

Mechanical vibration — Rotor balancing — Part 12: Procedures and tolerances for rotors with flexible behaviour (a nationally adopted international standard)

Secretariat:

Acoustical Society of America

Approved September 24, 2019 by:

American National Standards Institute, Inc.

Abstract

This nationally adopted international standard presents typical configurations of rotors with flexible behaviour in accordance with their characteristics and balancing requirements, describes balancing procedures, specifies methods of assessment of the final state of balance, and establishes guidelines for balance quality criteria. Can also serve as a basis for more involved investigations, e.g. when a more exact determination of the required balance quality is necessary. If due regard is paid to the specified methods of manufacture and balance tolerances, satisfactory running conditions can be expected. Is not intended to serve as an acceptance specification for any rotor, but rather to give indications of how to avoid gross deficiencies and unnecessarily restrictive requirements. Structural resonances and modifications thereof lie outside the scope of this document. The methods and criteria given are the result of experience with general industrial machinery. It is possible that they are not directly applicable to specialized equipment or to special circumstances. Therefore, in some cases, deviations from this document are possible.

AMERICAN NATIONAL STANDARDS ON ACOUSTICS

The Acoustical Society of America (ASA) provides the Secretariat for Accredited Standards Committees S1 on Acoustics, S2 on Mechanical Vibration and Shock, S3 on Bioacoustics, S3/SC 1 on Animal Bioacoustics, and S12 on Noise. These committees have wide representation from the technical community (manufacturers, consumers, trade associations, organizations with a general interest, and government representatives). The standards are published by the Acoustical Society of America through the American Institute of Physics as American National Standards after approval by their respective Standards Committees and the American National Standards Institute (ANSI).

These standards are developed and published as a public service to provide standards useful to the public, industry, and consumers, and to Federal, State, and local governments.

Each of the accredited Standards Committees (operating in accordance with procedures approved by ANSI) is responsible for developing, voting upon, and maintaining or revising its own Standards. The ASA Standards Secretariat administers Committee organization and activity and provides liaison between the Accredited Standards Committees and ANSI. After the Standards have been produced and adopted by the Accredited Standards Committees, and approved as American National Standards by ANSI, the ASA Standards Secretariat arranges for their publication and distribution.

An American National Standard implies a consensus of those substantially concerned with its scope and provisions. Consensus is established when, in the judgment of the ANSI Board of Standards Review, substantial agreement has been reached by directly and materially affected interests. Substantial agreement means much more than a simple majority, but not necessarily unanimity. Consensus requires that all views and objections be considered and that a concerted effort be made towards their resolution.

The use of an American National Standard is completely voluntary. Their existence does not in any respect preclude anyone, whether he or she has approved the Standards or not, from manufacturing, marketing, purchasing, or using products, processes, or procedures not conforming to the Standards.

NOTICE: This American National Standard may be revised or withdrawn at any time. The procedures of the American National Standards Institute require that action be taken periodically to reaffirm, revise, or withdraw this Standard.



Acoustical Society of America
Standards Secretariat
1305 Walt Whitman Road, Suite 300
Melville, New York 11747
Telephone: 1 (631) 390-0215
Fax: 1 (631) 923-2875
E-mail: asastds@acousticalsociety.org

© 2019 by Acoustical Society of America. This standard may not be reproduced in whole or in part in any form for sale, promotion, or any commercial purpose, or any purpose not falling within the provisions of the U.S. Copyright Act of 1976, without prior written permission of the publisher. For permission, address a request to the Standards Secretariat of the Acoustical Society of America.

These materials are subject to copyright claims of ISO and ASA. No part of this publication may be reproduced in any form, including an electronic retrieval system, without the prior written permission of ASA. All requests pertaining to this standard should be submitted to ASA.

Contents

1	Scope.....	1
2	Normative references	1
3	Terms and definitions.....	2
4	Fundamentals of dynamics and balancing of rotors with flexible behaviour.....	2
4.1	General	2
4.2	Unbalance distribution.....	2
4.3	Mode shapes of rotors with flexible behaviour.....	3
4.4	Response of a rotor with flexible behaviour to unbalance	4
4.5	Aims of balancing rotors with flexible behaviour	5
4.6	Provision for correction planes.....	6
4.7	Coupled rotors.....	6
5	Rotor configurations	6
6	Procedures for balancing rotors with flexible behaviour at low speed	9
6.1	General	9
6.2	Selection of correction planes.....	10
6.3	Service speed of the rotor.....	10
6.4	Initial unbalance.....	10
6.5	Low-speed balancing procedures	10
7	Procedures for balancing rotors with flexible behaviour at high speed.....	12
7.1	General	12
7.2	Installation for balancing.....	12
7.3	Procedure G — Multiple speed balancing.....	13
7.4	Procedure H — Service speed balancing	16
7.5	Procedure I — Fixed speed balancing.....	17
8	Evaluation criteria.....	17
8.1	Choice of criteria	17
8.2	Vibration limits in the balancing machine.....	18
8.3	Residual unbalance tolerances.....	21
9	Evaluation procedures	23
9.1	Evaluation procedures based on vibration limits	23
9.2	Evaluation based on residual unbalance tolerances	24

Annex A (informative) Cautionary notes concerning rotors when installed <i>in-situ</i>	28
A.1 General	28
A.2 Bearing misalignment.....	28
A.3 Radial and axial runout of coupling faces	28
A.4 Bearing instability	28
Annex B (informative) Optimum planes balancing — Low-speed three-plane balancing	29
Annex C (informative) Conversion factors	31
Annex D (informative) Example calculation of equivalent residual modal unbalances	33
D.1 Residual unbalance calculation.....	33
D.2 Influence coefficients.....	34
D.3 Final vibration readings	35
D.4 Residual unbalance at low speed, 1 000 r/min	36
D.5 Residual unbalance at 3 400 r/min.....	36
D.6 Residual unbalance at 9 000 r/min	36
Annex E (informative) Procedures to determine whether a rotor shows rigid or flexible behaviour	37
E.1 General	37
E.2 Determination of whether a rotor shows rigid or flexible behaviour.....	37
E.3 Rotor flexibility test	38
E.4 Evaluation of flexibility test data.....	39
Annex F (informative) Method of computation of unbalance correction	40
Bibliography	41

Tables

Table 1 — Rotors with flexible behaviour	7
Table C.1 — Typical conversion factors (see 8.2.6)	32
Table D.1 — Influence coefficients.....	35
Table D.2 — Final vibration readings	35
Table D.3 — Residual unbalance at 1 000 r/min	36
Table D.4 — Residual unbalance at 3 400 r/min	36
Table D.5 — Residual unbalance at 9 000 r/min	36

Figures

Figure 1 — Simplified mode shapes for rotors with flexible behaviour on flexible supports.....	3
Figure 2 — Examples of possible damped mode shapes	5
Table 2 — Balancing procedures.....	9
Figure B.1 — Graphical presentation for determination of H	30
Figure D.1 — Example gas turbine rotor	33
Figure D.2 — Run-up curve (before balancing).....	34
Figure F.1 — Vectorial effect of a trial mass set	40

Foreword

[This Foreword is for information only and is not a part of the American National Standard ANSI/ASA S2.81-2019/ Part 12/ISO 21940-12:2016 American National Standard Mechanical vibration – Rotor balancing – Part 12: Procedures and tolerances for rotors with flexible behaviour (a nationally adopted international standard). As such, this Foreword may contain material that has not been subjected to public review or a consensus process. In addition, it does not contain requirements necessary for conformance to the standard.]

This standard comprises a part of a group of definitions, standards, and specifications for use in mechanical vibration and shock. It was developed and approved by Accredited Standards Committee S2 Mechanical Vibration and Shock under its approved operating procedures. Those procedures have been accredited by the American National Standards Institute (ANSI). The Scope of Accredited Standards Committee S2 is as follows:

Standards, specification, methods of measurement and test, and terminology in the field of mechanical vibration and shock, and condition monitoring and diagnostics of machines, including the effects of exposure to mechanical vibration and shock on humans, including those aspects which pertain to biological safety, tolerance and comfort.

This standard is an identical national adoption of ISO 21940-12:2016 Mechanical vibration — Rotor balancing —Part 12: Procedures and tolerances for rotors with flexible behaviour, which was prepared by ISO/TC 108/SC 2.

The ANSI/ASA equivalents to ISO/IEC standards referenced herein are given below:

- ANSI/ASA S2.1/ISO 2041 is an identical national adoption of ISO 2041.
- ANSI/ASA S2.80/Part 1/ISO 20816-1 is an identical national adoption of ISO 20816-1.
- ANSI/ASA S2.81/Part 11/ISO 21940-11 is an identical national adoption of ISO 21940-11.
- ANSI/ASA S2.81/Part 14/ISO 21940-14 is an identical national adoption of ISO 21940-14.

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

James T. Nelson, *Chair*
Richard J. Peppin, *Vice-Chair*

Nancy Blair-DeLeon, *Secretary*

Acoustical Society of America James T. Nelson
..... Richard J. Peppin (Alt.)

Association of American Railroads George Page
..... Jeffrey Moller (Alt.)

Calnetix Larry A. Hawkins
..... Rasish Khatri (Alt.)

Caterpillar, Inc. Daniel G. Roley
..... Charles Crowell (Alt.)

Eckardt Johanning, MD, P.C. Eckardt Johanning

Emerson Electric – Copeland Corporation	Ali T. Herfat
FLIR Systems	Ronald Lucier
Logan Mullinix Consulting	Logan Mullinix
Mechanical Solutions, Inc.	William D. Marscher
.....	Maki Onari (Alt.)
National Institute for Occupational Safety and Health (NIOSH)	Renguang Dong
.....	Thomas W. McDowell (Alt.)
National Institute of Standards & Technology	Michael Gaitan
Northern Illinois University	Donald Peterson
PCB Group	Nicholas Fulciniti
.....	Chad M. Walber (Alt.)
Power Tool Institute, Inc.	William D. Spencer
.....	Mark Hickok (Alt.)
Siemens Power Generation, Inc.	Max L'vov
UE Systems, Inc.	Mark Goodman
U.S. Air Force	Suzanne D. Smith
U.S. Army Public Health Command	Steven Chervak
.....	Jay Clasing (Alt.)
U.S. Naval Surface Warfare Center – Carderock	Jason Smoker
.....	Diedre Gilmer (Alt.)
University of Washington	Peter Johnson
VibeTech, Inc.	Jeff Leismer
Vibration Institute	Ronald L. Eshleman
.....	Brian Biby (Alt.)
Z-R Consulting	Zlatan Racic
.....	Marin Racic (Alt.)

Individual Experts of Accredited Standards Committee S2, Mechanical Vibration and Shock, were:

Anthony Brammer
George Johnson
Robert Koch

Richard J. Peppin
Donald Wasserman

Working Group S2/WG 10, Operational Monitoring and Condition Evaluation, which assisted Accredited Standards Committee S2, Mechanical Vibration and Shock, in the development of this standard, had the following membership.

Max L'vov, Chair

David P. Butchy
Art J. Cautilli
Eric J. Lambert

Mark T. McGown
John Niemkiewicz
Rajagopal Subbiah

Thomas Turek
John J. Weil
Marion Williams

Suggestions for improvements to this standard will be welcomed. They should be sent to Accredited Standards Committee S2, Mechanical Vibration and Shock, in care of the Standards Secretariat of the Acoustical Society of America, 1305 Walt Whitman Road, Suite 300, Melville, New York 11747. Telephone: 631-390-0215; FAX: 631-923-2875; E-mail: asastds@acousticalsociety.org.

Introduction

The aim of balancing any rotor is to achieve satisfactory running when installed *in-situ*. In this context, “satisfactory running” means that not more than an acceptable magnitude of vibration is caused by the unbalance remaining in the rotor. In the case of a rotor with flexible behaviour, it also means that not more than an acceptable magnitude of deflection occurs in the rotor at any speed up to the maximum service speed.

Most rotors are balanced in manufacture prior to machine assembly because afterwards, for example, there might be only limited access to the rotor. Furthermore, balancing of the rotor is often the stage at which a rotor is approved by the purchaser. Thus, while satisfactory running *in-situ* is the aim, the balance quality of the rotor is usually initially assessed in a balancing machine. Satisfactory running *in-situ* is, in most cases, judged in relation to vibration from all causes, while in the balancing machine, primarily, once-per-revolution effects are considered.

This part of ISO 21940 classifies rotors in accordance with their balancing requirements and establishes methods of assessment of residual unbalance.

This part of ISO 21940 also shows how criteria for use in the balancing machine can be derived from either vibration limits specified for the assembled and installed machine or unbalance limits specified for the rotor. If such limits are not available, this part of ISO 21940 shows how they can be derived from ISO 10816 and ISO 7919 if desired in terms of vibration, or from ISO 21940-11, if desired in terms of permissible residual unbalance. ISO 21940-11 is concerned with the balance quality of rotating rigid bodies and is not directly applicable to rotors with flexible behaviour because rotors with flexible behaviour can undergo significant bending deflection. However, in this part of ISO 21940, methods are presented for adapting the criteria of ISO 21940-11 to rotors with flexible behaviour.

There are situations in which an otherwise acceptably balanced rotor experiences an unacceptable vibration level *in situ*, owing to resonances in the support structure. A resonance or near resonance condition in a lightly damped structure can result in excessive vibratory response to a small unbalance. In such cases, it can be more practicable to alter the natural frequency or damping of the structure rather than to balance to very low levels, which might not be maintainable over time (see also ISO 21940-31).

American National Standard

Mechanical vibration — Rotor balancing — Part 12: Procedures and tolerances for rotors with flexible behaviour

1 Scope

This part of ISO 21940 presents typical configurations of rotors with flexible behaviour in accordance with their characteristics and balancing requirements, describes balancing procedures, specifies methods of assessment of the final state of balance, and establishes guidelines for balance quality criteria.

This part of ISO 21940 can also serve as a basis for more involved investigations, e.g. when a more exact determination of the required balance quality is necessary. If due regard is paid to the specified methods of manufacture and balance tolerances, satisfactory running conditions can be expected.

This part of ISO 21940 is not intended to serve as an acceptance specification for any rotor, but rather to give indications of how to avoid gross deficiencies and unnecessarily restrictive requirements.

Structural resonances and modifications thereof lie outside the scope of this part of ISO 21940.

The methods and criteria given are the result of experience with general industrial machinery. It is possible that they are not directly applicable to specialized equipment or to special circumstances. Therefore, in some cases, deviations from this part of ISO 21940 are possible.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 1925¹, *Mechanical vibration — Balancing — Vocabulary*

ISO 2041, *Mechanical vibration, shock and condition monitoring — Vocabulary*

ISO 21940-11², *Mechanical vibration — Rotor balancing — Part 11: Procedures and tolerances for rotors with rigid behaviour*

¹ To become ISO 21940-2 when revised.