Reference Standards for Machinery Vibration Analysis & Condition Monitoring

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ABSTRACT

Standards are criteria established by authority, custom, or general consent. Good reference standards represent a broad consensus of opinion among users, and are therefore widely accepted and applied. Furthermore, standards should be clear, concise, and easily understood. Numerous standards exist or are under development to guide or govern condition monitoring and analysis, including some that establish classifications for machinery vibration, how measurements should be made, and how the acquired data should be analyzed. This paper will introduce a selection of applicable reference standards, and provide commentary and opinion on each with respect to features and applications.

Keywords: standards, vibration, condition monitoring

1. INTRODUCTION

Standards are documented agreements containing technical specifications or other precise criteria to be used consistently as rules, guidelines, or definitions of characteristics, to ensure that materials, products, processes and services are fit for their purpose. A good standard represents consensus of opinion, is easy to use, and contains no ambiguities or loopholes.

2. ISO STANDARDS FOR VIBRATION MONITORING AND ANALYSIS

2.1 The ISO Standards System

In the field of machinery vibration monitoring and analysis, a variety of relevant standards are developed and published by ISO (International Organization for Standardization). ISO is a worldwide federation of national standards bodies from 145 countries, and considers itself a bridge between the public and private sectors. A *member body* of ISO is the national body "most representative of standardization in its country". Only one such body for each country is accepted for ISO membership. Member bodies are entitled to participate and exercise full voting rights on any technical committee of ISO.

In addition to ISO, various trade organizations such as National Electrical Manufacturers Association (NEMA) and American Petroleum Institute (API) have developed and published vibration standards, which are widely accepted and applied (and therefore relevant). In most cases, these standards have been developed by consensus of consumers and manufacturers, and their use is considered voluntary.

ISO standards are developed by *technical committees* comprised of experts on loan from the industrial, technical, and business sectors. The experts participate as national delegations, selected by the ISO national member institute for their respective countries. Technical committees meet to discuss, debate, and argue until they reach consensus on a draft agreement,

which is circulated as a Draft International Standard (DIS) to all ISO members for comment and balloting. After taking into account any feedback, the ISO members formulate their position on the draft standard. Following an affirmative vote[†], the document, including any modifications, is re-circulated to the ISO members as a Final Draft International Standard (FDIS) for 2nd ballot. If that vote is positive, the document is then published by ISO as an International Standard.

Most of the ISO standards for machinery vibration monitoring and analysis are guided by technical committee TC108, Mechanical vibration and shock. TC108 is comprised of 21 Participating (P-member) countries and 27 Observer countries. As of August 2007, there are a total of 134 published ISO standards related to TC108 and its SCs (subcommittees). Noteworthy subcommittees include; SC2, Measurement and evaluation of mechanical vibration and shock as applied to machines, vehicles and structures, and SC5, Condition monitoring and diagnostics of machines.

The stated scope of TC108 is "Standardization in the fields of mechanical vibration and shock and the effects of vibration and shock on humans, machines, vehicles (air, sea, land and rail) and stationary structures, and of the condition monitoring of machines and structures, using multidisciplinary approaches."

Specific areas of current interest include the standardization of:

- terminology and nomenclature in the fields of mechanical vibration, mechanical shock and condition monitoring;
- measurement, analysis and evaluation of vibration and shock e.g. signal processing methods, structural dynamics analysis methods, transducer and vibration generator calibration methods, etc.;
- active and passive control methods for vibration and shock, e.g. balancing of machines, isolation and damping;
- evaluation of the effects of vibration and shock on humans, machines, vehicles (air, sea, land and rail), stationary structures and sensitive equipment;
- vibration and shock measuring instrumentation, e.g. transducers, vibration generators, signal conditioners, signal analysis instrumentation and signal acquisition systems;
- measurement methods, instrumentation, data acquisition, processing, presentation, analysis, diagnostics and prognostics, using all measurement variables required for the condition monitoring of machines;
- training and certification of personnel in relevant areas.

2.2 ISO Standards For Evaluation Of Vibration Severity

Standards for evaluation of vibration severity are considered one of the most important activities of ISO/TC108. Unfortunately, due to the range of machinery categories and classifications, it may also be the most confusing. A wide variety of published standards describe acceptable vibration limits, including the **ISO/7919** series (5 parts) "Mechanical vibration of non-

reciprocating machines – Measurements on rotating shafts and evaluation criteria" and the **ISO/10816** series (7 parts) "Mechanical vibration – Evaluation of machine vibration by measurements on non-rotating parts"

As detailed in Table 1, ISO 7919-1 is the basic document describing the general requirements for measurement and evaluation of machinery vibration using shaft measurements. Similarly, ISO 10816-1 is the basic document describing the general requirements for evaluating machinery vibration using casing and/or foundation measurements. Subsequent parts of each series of documents apply to different classes and types of machinery, and include specific evaluation criteria used to assess vibration severity.

† In accordance with ISO directives, Part 1, Procedures, 2001, an enquiry draft (DIS) is approved if
a) a two-thirds majority of the votes cast by P-members of the technical committee or subcommittee are in favour, and
b) not more than one quarter of the total votes cast are negative.

ISO 7919 Series	**Mechanical vibration of non-reciprocating machines - Measurement on rotating shafts and evaluation criteria**
7919-1:1996	Part 1: General Guidelines
7919-2: 2001	Part 2: Land-based steam turbines and generators in excess of 50 MW with normal operating speeds of 1500 r/min, 1800 r/min, 3000 r/min and 3600 r/min
7919-3: 1996	Part 3: Coupled industrial machines
NP 7919-4	Part 4: Gas turbine sets
7919-5: 2005	Part 5: Machines set in hydraulic power generating and pumping plants
ISO 10816 Series	**Mechanical vibration - Evaluation of machine vibration by measurements on non-rotating parts**
10816-1: 1995	Part 1: General Guidelines
10816-2: 2001	Part 2: Land-based steam turbines and generators in excess of 50 MW with normal operating speeds of 1500 r/min, 1800 r/min, 3000 r/min and 3600 r/min
10816-3: 1998	Part 3: Industrial machines with normal power above 15kW and nominal speeds between 120 r/min and 15000 r/min when measured in situ
NP 10816-4	Part 4: Gas turbine sets excluding aircraft derivatives
10816-5: 2000	Part 5: Machines set in hydraulic power generating and pumping plants
10816-6: 1995	Part 6: Reciprocating machines with power ratings above 100 kW
DIS 10816-7‡	Part 7: Rotodynamic pumps for industrial application

Table 1 • ISO Standards for Evaluation of Vibration Severity†

The evaluation procedures in the ISO/7919 and ISO/10816 series of standards are limited to broadband measurements, without reference to frequency components or phase§. Measurement procedures are detailed in Part 1: General Guidelines of each series, including shaft relative, shaft absolute, and pedestal vibration measurements.

At the May 13 – 16, 2003 meeting of ISO/TC108/SC2, Professor Hiroshi Kanki of Japan proposed "Guidelines for selecting vibration evaluation methods by measurement on the rotating shaft and/or on non-rotating parts", referred to as the "umbrella document". The scope of the umbrella document is to provide general guidelines for selecting the appropriate vibration

standards for a specific machinery classification. The proposed method includes 2 key evaluation criteria; 1) shaft displacement from the journal centerline, and 2) stiffness ratio of pedestal to bearing (which determines the ratio of the shaft relative vibration to the pedestal vibration), as detailed in Figures 1 and 2, below.

This was proposed as a work item, and will essentially become a standard on how to select and apply the standards (proposed by ISO/TC108/WG2 as Part 0 of ISO/7919 and/or ISO 10816).

† Early ISO vibration severity standards, ISO/2372, ISO 2954, and ISO 3945 "Mechanical vibration of large rotating machines with speed range from 10 to 200 r/s – Measurement and evaluation of vibration severity in situ", have been superseded by the ISO 7919 and 10816 series.

‡ ISO/10816-7 was developed by Joint Working Group (JWG) 9 of ISO/TC108/SC2 and ISO/TC115 (Pumps), and is presently at the Committee Stage. The Committee Draft (CD) was circulated to P-member countries for comment and vote in January 2003.

§ Narrowband measurements and spectral analysis are to be dealt with in the ISO/13373 series "Condition monitoring and diagnostics of machines – Vibration condition monitoring".

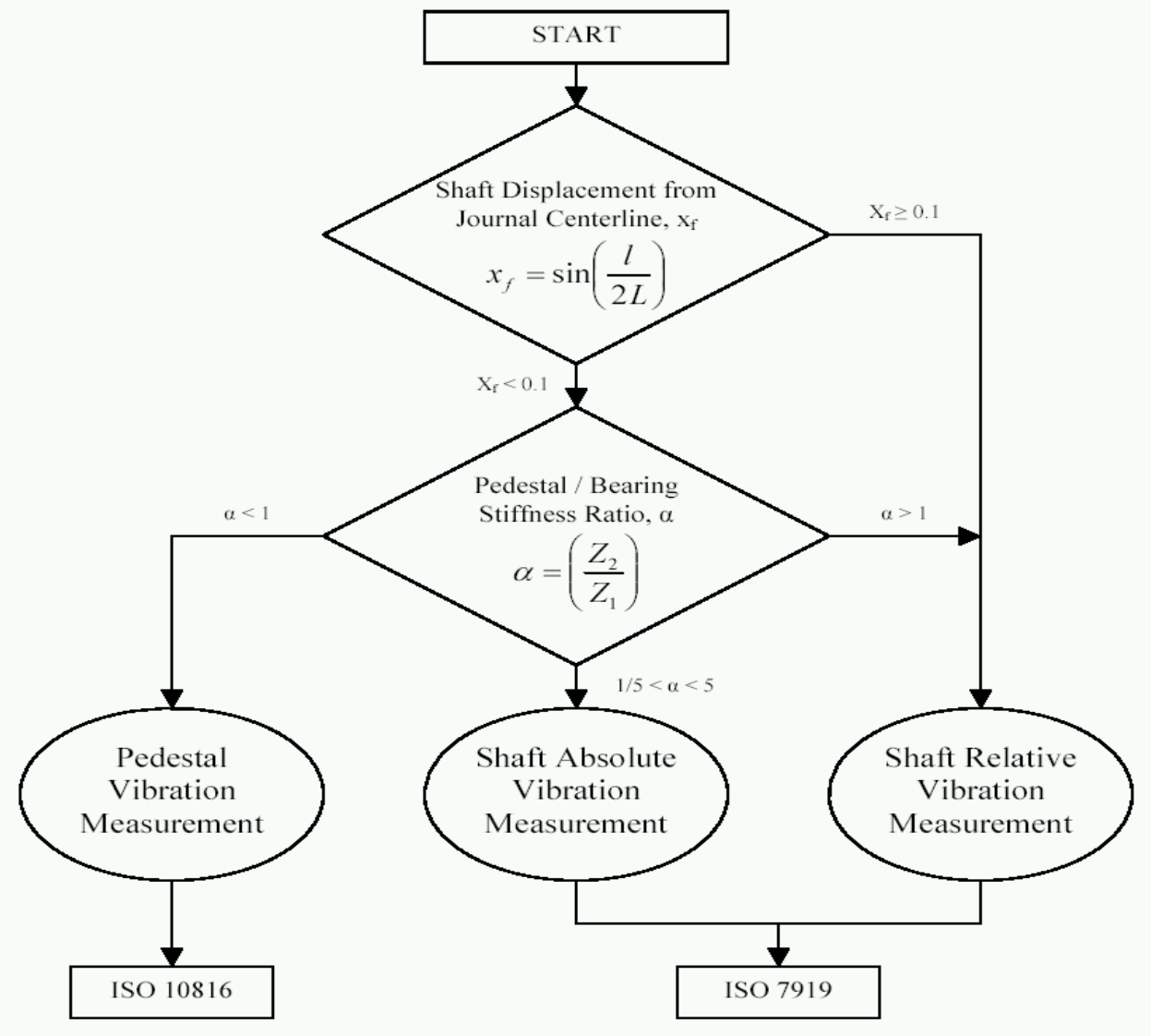

Figure 1 • Flow Diagram for selection of measurements and evaluation of vibration severity

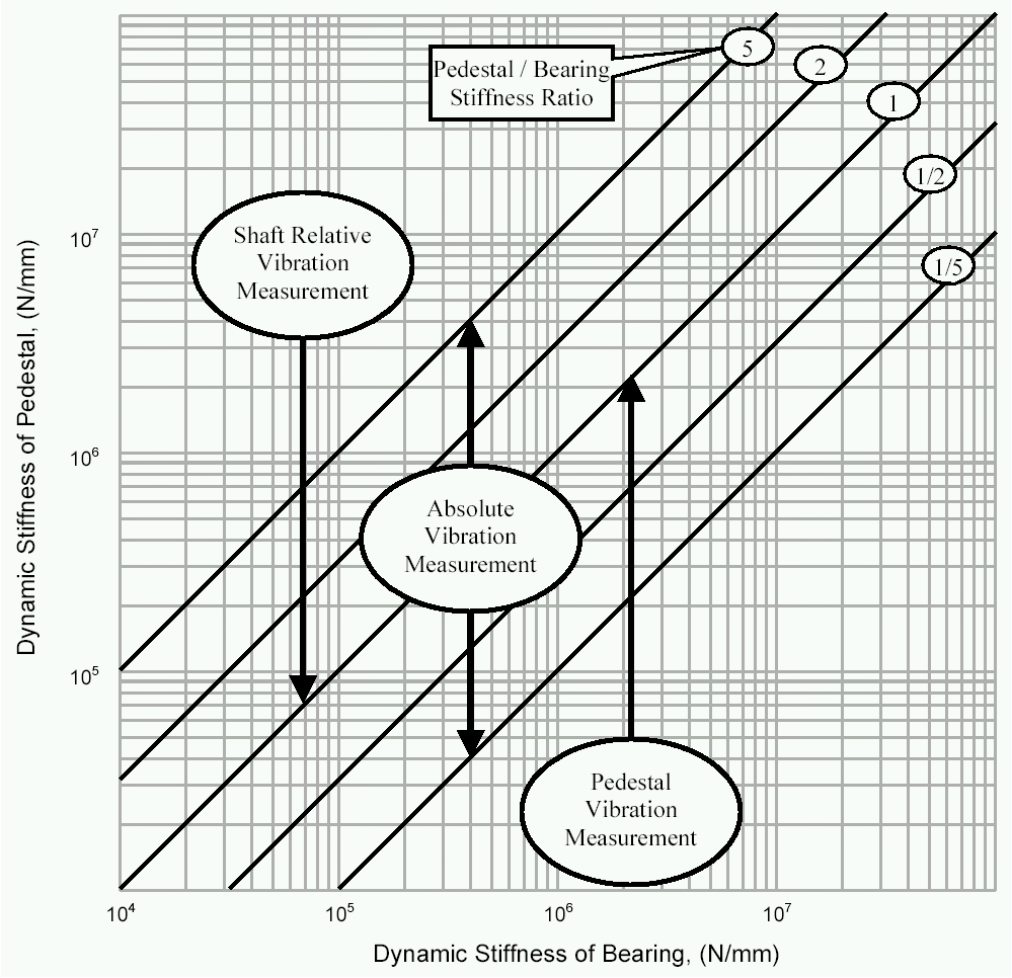

Figure 2 • Dynamic Stiffness Ratio Diagram

In general, machines equipped with rolling element bearings will tend to have high bearing stiffness, a stiffness ratio less than 1, and are better suited to vibration measurements at the pedestal and/or casing. Conversely, machines using fluid film bearings and supported on relatively soft pedestals, will have a much higher stiffness ratio, and are better suited to shaft vibration measurements.

Table 2, below, shows example dynamic stiffness ratios, and the applicable reference standard.

Machine	Dynamic Stiffness Ratio, α	ISO 10816 (pedestal)	ISO 7919 (shaft)
High Pressure Turbine	5	Moderate	Good
Low Pressure Turbine	1.5	Moderate	Good
Large Generator	1.5	Moderate	Good
High Pressure Centrifugal Compressor	5	Not Good	Good
Large Fan	2/3	Good	Moderate
Small Fan & Pump	1/3	Good	Moderate
Vertical Pump	1/10	Good	Not Good
Large Steam Turbine Generator Set	1.5 to 3	Moderate	Good

Table 2 • Example ISO Standards selection guideline

Vibration Magnitude is defined within this group of standards as the maximum value of the broadband rms velocity in the specified frequency range (typically from 10 to 1,000 Hz), as evaluated on the structure at prescribed points. Note that other quantities such as displacement or acceleration and peak values instead of rms values are permitted, but may not easily correlate to criteria based on rms values. Evaluation criteria to assess vibration severity include both vibration magnitude and changes in vibration magnitude. As shown in Figure 3 and Table 3, below, evaluation zones are defined to permit a qualitative assessment of the vibration, and to provide guidelines on possible actions.

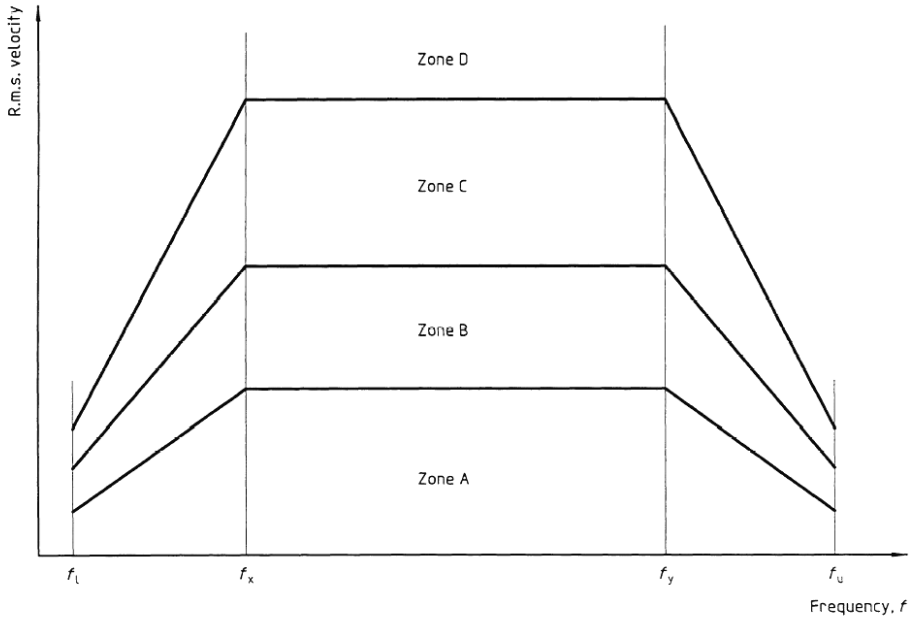

Figure 3 • General Form of Vibration Evaluation Criteria

R.m.s. vibration velocity mm/sec	up to 15 kW Class I	15 to 75 kW Class II	> 75 kW (rigid) Class III	> 75 kW (soft) Class IV
0,28	A	A	A	A
0,45				
0,71				
1,12	B			
1,8		B		
2,8	C		B	
4,5		C		B
7,1	D		C	
11,2		D		C
18			D	
28				D
45				

Table 3 • Typical Evaluation Criteria Zone Vibration Magnitude

As shown in Table 1, different classes and types of machinery are addressed in subsequent parts of ISO 7919 and 10816, including evaluation criteria. As a “short-term expedient only” limited evaluation criteria are provided in an informative annex of Part 1of each standard (Table 3).

2.3 ISO Standards For Vibration Measurements

ISO 13373-1:2001 Condition monitoring and diagnostics of machines — Vibration condition monitoring — Part1: General procedures provides general guidelines for the measurement of machinery vibration for condition monitoring. Recommendations are provided for the following;

- measurement methods and parameters
- transducer selection, location, and attachment
- data collection
- machine operating conditions
- vibration monitoring systems
- signal conditioning systems
- interfaces with data processing systems
- continuous and periodic monitoring

Due to the wide variety of approaches to condition monitoring, specific topics will be addressed in more detail in additional parts of 13373. At the time of writing this article, Part 2: Processing, analysis and diagnostics is at the committee draft stage.

ISO 17359:2003 Condition monitoring and diagnostics of machines — General guidelines sets out guidelines for the general procedures to be considered when setting up a condition monitoring program.

2.4 ISO Standards For Training and Certification

ISO standards for personnel training and certification are a relatively new and significant initiative for ISO/TC108. In August, 2003, **ISO 18436-2:2003** Condition monitoring and diagnostics of machines — Requirements for training and certification of personnel — Part 2: Vibration condition monitoring and diagnostics received an affirmative vote at the FDIS stage, and was affirmed as an international standard. 18436-2 describes a 4-category scheme for certification of vibration analysis personnel who perform condition monitoring and diagnostics. Certification candidates are required to meet prerequisite education, training, and experience, and successfully pass a qualification examination.

Future parts of the 18436 series will include;

1. Part 1: Requirements for certifying bodies and the certification process
2. Part 3: Requirements for training bodies
3. Part 4: Lubrication management and analysis
4. Part 5: Thermography
5. Part 6: Diagnostics and prognostics
6. Part 7: Condition monitoring specialists
7. Part 8: Balancing

The normative Annex B from 18236-2 – Applicable International Standards, is included with this article as an appendix.

3. OTHER STANDARDS FOR VIBRATION MONITORING AND ANALYSIS

3.1 American Petroleum Institute (API) Standards

API produces a wide range of documents, including reference standards which are well suited for shop testing of new and rebuilt machinery. Note that these standards generally apply to equipment for use in the petrochemical industries. Table 4, below, shows a selection of API standards.

Equipment Type	API Standard	Acceptance Test	Other Requirements
Pumps	610 (9TH edition March '03)	Shaft Relative + Casing	Vertical Pump (0.20 ips pk)
Fans	673 (2ND edition November '01)	Casing (0.1 ips pk)	
Steam Turbines	612 (4TH edition June '95)	Shaft Relative (mil pk-pk)	4 hour run in test required
Gears	613 (5TH edition March '03)	Casing (0.15 ips pk)	Unbalance 4 W/N oz-in
Centrifugal Compressors	617 (7TH edition July '02)	Shaft Relative (mil pk-pk)	4 hour run in test required
Screw Compressors	619 (3RD edition June '97)	Shaft Relative (mil pk-pk)	Unbalance 4 W/N oz-in
Induction Motors (/ 250 hp)	541 (4Th edition March '03)		Unbalance 4 W/N oz-in

Table 4 • Sample API Standards for Accptance Testing

3.2 National Building Code (1995) and Steel Design Code CAN/CSA-S16.1

2 applicable, but often ignored reference standards, are the NBC and Steel Design Code. Each of these important standards make specific reference to the problem of structural resonance, and state that a dynamic analysis may be required.

3. CONCLUSION

There is a growing impact of standards on global commerce and the potential for standards to either facilitate or impede international trade. As trade barriers have lowered (through trade agreements such as NAFTA and WTO) the focus has changed from the development of national standards to regional and international standards, which are subsequently adopted with or without adjustments for unique regional conditions. The development of standards, arrived at through international consensus, facilitate trade and ensure free and equitable access to international markets.

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Orbit - Bently Publishing Co., Minden, NV, (June 1998)

Appendix A • excerpt from 18436-2:2003(E)

Annex B
(normative)

Applicable International Standards

ISO reference	Category			
	I	II	III	IV
ISO 1925, *Mechanical vibration — Balancing — Vocabulary*		•	•	•
ISO 1940-1, *Mechanical vibration — Balance quality requirements of rigid rotors — Part 1: Specification and verification of balance tolerances*		•	•	•
ISO 1940-2, *Mechanical vibration — Balance quality requirements of rigid rotors — Part 2: Balance errors*			•	•
ISO 2017, *Mechanical vibration and shock — Resilient mounting systems — Part 1: Application of source and receiver isolation*				•
ISO 2041, *Vibration and shock — Vocabulary*		•	•	•
ISO 2954, *Mechanical vibration of rotating and reciprocating machinery — Requirements for instruments for measuring vibration severity*				•
ISO 5348, *Mechanical vibration and shock — Mechanical mounting of accelerometers*		•	•	•
ISO 7919-1, *Mechanical vibration of non-reciprocating machines — Measurement on rotating shafts and evaluation criteria — Part 1: General guidelines*	•	•	•	•
ISO 7919-2, *Mechanical vibration — Evaluation of machine vibration by measurements on rotating shafts — Part 2: Land-based steam turbines and generators in excess of 50 MW with normal operating speeds of 1 500 r/min, 1 800 r/min, 3 000 r/min and 3 600 r/min*		•	•	•
ISO 7919-3, *Mechanical vibration of non-reciprocating machines — Measurements on rotating shafts and evaluation criteria — Part 3: Coupled industrial machines*		•	•	•
ISO 7919-4, *Mechanical vibration of non-reciprocating machines — Measurements on rotating shafts and evaluation criteria — Part 4: Gas turbine sets*		•	•	•
ISO 7919-5, *Mechanical vibration of non-reciprocating machines — Measurements on rotating shafts and evaluation criteria — Part 5: Machine sets in hydraulic power generating and pumping plants*		•	•	•
ISO 8528-9, *Reciprocating internal combustion engine driven alternating current generating sets — Part 9: Measurement and evaluation of mechanical vibrations*		•	•	•
ISO 8569, *Mechanical vibration and shock — Measurement and evaluation of shock and vibration effects on sensitive equipment in buildings*			•	•
ISO 10816-1, *Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts — Part 1: General guidelines*	•	•	•	•

Appendix A • excerpt from 18436-2:2003(E)

ISO reference	Category			
	I	II	III	IV
ISO 10816-2, *Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts — Part 2: Land-based steam turbines and generators in excess of 50 MW with normal operating speeds of 1 500 r/min, 1 800 r/min, 3 000 r/min and 3 600 r/min*		•	•	•
ISO 10816-3, *Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts — Part 3: Industrial machines with nominal power above 15 kW and nominal speeds between 120 r/min and 15 000 r/min when measured in situ*		•	•	•
ISO 10816-4, *Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts — Part 4: Gas turbine driven sets excluding aircraft derivatives*		•	•	•
ISO 10816-5, *Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts — Part 5: Machine sets in hydraulic power generating and pumping plants*		•	•	•
ISO 10816-6, *Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts — Part 6: Reciprocating machines with power ratings above 100 kW*		•	•	•
ISO 11342, *Mechanical vibration — Methods and criteria for the mechanical balancing of flexible rotors*				•
ISO 13372, *Condition monitoring and diagnostics of machines — Vocabulary*	•	•	•	•
ISO 13373-1, *Condition monitoring and diagnostics of machines — Vibration condition monitoring — Part 1: General procedures*	•	•	•	•
ISO 13379, *Condition monitoring and diagnostics of machines — General guidelines on data interpretation and diagnostics techniques*			•	•
ISO 14694, *Industrial fans — Specifications for balance quality and vibration levels*	•	•	•	•
ISO 14695, *Industrial fans — Method of measurement of fan vibration*			•	•
ISO 17359, *Condition monitoring and diagnostics of machines — General guidelines*	•	•	•	•
ISO 18436-1, *Condition monitoring and diagnostics of machines — Requirements for training and certification of personnel — Part 1: Requirements for certifying bodies and the certification process*				•