STANDARD

ANSI/AMCA Standard 204-20

Balance Quality and Vibration Levels for Fans

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Air Movement and Control Association International

AMCA Corporate Headquarters
30 W. University Drive, Arlington Heights, IL 60004-1893, USA
communications@amca.org ▪ Ph: +1-847-394-0150 ▪ www.amca.org

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Air Movement and Control Association International
30 West University Drive
Arlington Heights, Illinois
60004

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AMCA International
30 West University Drive
Arlington Heights, IL 60004-1893
U.S.A.

European AMCA
Avenue des Arts, numéro 46
à Bruxelles (1000 Bruxelles)

Asia AMCA Sdn Bhd
No. 7, Jalan SiLC 1/6,
Kawasan Perindustrian SiLC Nusajaya,
Mukim Jelutong, 79200 Nusajaya, Johor
Malaysia

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Contents

1. Purpose **1**

2. Scope **1**

3. Normative References **1**

4. Definitions/Symbols **2**
4.1 Definitions 2
4.2 Symbols 5

5. Units of Measure **5**

6. Application Categories **5**

7. Balancing **6**
7.1 Balance quality grades 6
7.2 Permissible residual unbalance 7

8. Vibration **8**
8.1 Measurement requirements 8
8.2 Fan support system 12
8.3 Factory tests 12
8.4 Vibration limits for operation in situ 12

9. Other Rotating Components **13**

10. Documentation **14**
10.1 Balance 14
10.2 Vibration 14

Annex A SI/I-P Converion Table (Informative) **15**

Annex B Relationships (Informative) **16**

Annex C Maximum Permissable Residual Imbalance (Informative) **19**

Annex D Instruments & Calibration (Informative) **21**
D.1 Instruments 21
D.2 Calibration 21

Annex E Digital Overall Vibration Calculation (Informative) **22**

Annex F References (Informative) **23**

Balance Quality and Vibration Levels for Fans

1. Purpose

This standard addresses the subjects of fan balance and vibration (BV). It is part of a series of standards and publications listed in Annex F that cover important aspects related to fan design, manufacture and use.

Other standards exist that deal with machine vibration in general. This standard only considers fans. Vibration is recognized to be an important parameter regarding fan mechanical operation. Balance quality is a precondition to satisfactory mechanical operation.

The purpose of this standard is to define appropriate fan balance quality and operating vibration levels to individuals who specify, manufacture, use and maintain fans.

2. Scope

This standard covers fans with rigid rotors generally found in commercial heating, ventilating and air conditioning; industrial process applications; mine/tunnel ventilation applications; and power generation applications. Other applications are not specifically excluded, except as follows:

- Installations that involve severe forces, impacts or extreme temperatures acting on the fan are excluded.
- Fan foundations and installation practices are beyond this standard's scope. Foundation design and fan installation are not normally the fan manufacturer's responsibility. It is fully expected that the foundation upon which the fan is mounted will provide the support and stability necessary to meet the vibration criteria of the fan as-is from the factory.
- Other factors, such as impeller cleanliness, aerodynamic conditions, background vibration, operation at rotational speeds other than those agreed upon and fan maintenance, affect fan vibration levels but are beyond this standard's scope.
- This standard is intended to cover only the fan's balance or vibration and does not consider the effect of fan vibration on personnel, equipment or processes.

Any or all portions of this standard or modifications thereof are subject to agreement between the concerned parties.

3. Normative References

The following standards contain provisions that, through specific reference in this text, constitute provisions of this standard. At the time of this standard's publication, the editions indicated were valid.

All standards are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards listed below.

ISO 21940-2:2017, Mechanical vibration — Rotor balancing — Part 2: Vocabulary
ISO 21940-11:2016, Mechanical vibration — Rotor balancing — Part 11: Procedures and tolerances for rotors with rigid behavior
ISO 21940-21:2012, Mechanical vibration — Rotor balancing — Part 21: Description and evaluation of balancing machines

4. Definitions/Symbols

4.1 Definitions

4.1.1 Amount of unbalance
Product of the unbalance mass and the radial distance of its center of mass from the journal axis.

4.1.2 Balancing
The process of adding or removing mass in a plane or planes on a rotor to move the center of gravity toward the axis of rotation.

4.1.3 Balance quality grade
The recommended limits for residual unbalance of a rotor based upon the intended application. (Commonly used balance quality grades in ISO 21940-11:2016 refer to the vibration that would result if the rotor operated in free space; e.g., Balance Quality Grade G6.3 corresponds to a shaft vibration of 6.3 mm/s velocity at the operating rotational speed of the rotor.) The value represents the product of the unbalance multiplied by the angular velocity and divided by the weight of the rotor.

4.1.4 Displacement
The distance that a body moves from a stationary or neutral position.

4.1.5 Electrical run-out
The total measured variation in the apparent location of a ferrous shaft surface during a complete slow rotation of that shaft as determined by an eddy current probe system. This measurement may be affected by variations in the electrical/magnetic properties of the shaft material as well as variations in the shaft surface.

4.1.6 Fan application category
A grouping used to describe fan applications, their appropriate balance quality grades and recommended vibration levels.

4.1.7 Fan assembly
The fan assembly consists of those items typically packaged together as a complete fan including, as applicable, rotor, bearings, belts, housing, motor, sheaves and mounting base/structure. In the case of a cooling tower application, the fan assembly is considered to consist of the rotor alone.

4.1.8 Fan rotor
An assembly consisting of a fan impeller mounted on its shaft or bearings (ANSI/AMCA Standard 99).

4.1.9 Fan vibration level
The vibration amplitude measured at a fan bearing and expressed in units of displacement or velocity.

4.1.10 Filter
A device used to separate vibration based on its frequency. Vibration meters normally have adjustable filters to allow measurements at a frequency range of interest.

4.1.11 Filter-in; sharp
Vibration measured only at a frequency of interest.

4.1.12 Filter-out; broad pass
Vibration measured over a wide frequency range (typically 10-1,000 Hz); sometimes called overall vibration.

4.1.13 Flexible support
A fan support system designed so that the first natural frequency of the support is well below the frequency corresponding to the fan's operating rotational speed. Often, this involves compliant elastic elements between the fan and the support structure. According to the National Electrical Manufacturers Association (NEMA), "This condition is achieved by suspending the machine on a spring or by mounting on an elastic support (springs, rubber, etc.). The

natural oscillation frequencies of the suspension and machine are typically less than 33% of the frequency corresponding to the lowest speed of the machine under test" (NEMA MG 1-2016, sec. 7.6.2).

4.1.14 Foundation
Refers to the component to which the fan is mounted that provides the necessary support. A fan foundation must have sufficient mass and rigidity to avoid vibration amplification.

4.1.15 Frequency
In cyclical motion, the number of cycles per second (Hz) or cycles per minute (cpm).

4.1.16 Mechanical run-out
The total actual variation in the location of a rotor surface during a complete slow rotation of the rotor as determined by a stationary measurement device, such as a dial indicator.

4.1.17 Journal
Part of a rotor that is supported radially or guided by a bearing in which it rotates.

4.1.18 Journal axis
Mean straight line joining the centroids of cross-sectional contours of a journal.

4.1.19 Journal centers
Intersection of the journal axis and the radial plane of the journal where the resultant transverse bearing force acts.

4.1.20 Mil
A unit of measure that describes displacement. One mil equals one-thousandth of an inch (1 mil = 0.001 in.).

4.1.21 Overall fan vibration
See Section 4.1.12: filter-out; broad pass.

4.1.22 Peak (pk)
A displacement, velocity or acceleration value occurring at the maximum deviation from a zero or stationary value. See Figure 4.1.

4.1.23 Peak-to-peak (pk-pk)
The total range traversed in one cycle. Peak-to-peak readings apply to displacement only.

4.1.24 Residual unbalance
Unbalance of any kind that remains after balancing.

4.1.25 Rigid support
A fan support system designed so the system's first natural frequency is well above the frequency corresponding to the fan's operating rotational speed. NEMA notes, "The rigidity of a foundation is a relative quantity. It must be considered in conjunction with the rigidity of the machine bearing system. The ratio of bearing housing vibration to foundation vibration is a characteristic quantity for the evaluation of foundation flexibility influences. A foundation may be considered massive if the vibration amplitude of the foundation (in any direction) near the machine's feet or base frame is less than 25% of the maximum amplitude that is measured at the adjacent bearing housing in any direction" (NEMA MG 1-2016, sec. 7.6.2).

4.1.26 Rigid rotor behavior
The flexure caused by a rigid rotor's unbalance distribution can be neglected with respect to the agreed unbalance tolerance at any speed up to the maximum service speed. A rotor that behaves as rigid under one set of conditions (e.g., service speed, initial unbalance and unbalance tolerances) may not behave as rigid under another set of conditions.

4.1.27 RMS
The root-mean-square (RMS) value. For true sinusoidal motion, the RMS value is equal to 0.707 times the peak value.

4.1.28 Rotor
A body capable of rotation, generally with journals that are supported by bearings.

4.1.29 Rotor axis
Line joining the journal centers that follows the deflected shape of the rotor due to gravity or any other constant force.

4.1.30 Speed, balancing
Angular velocity at which rotor balancing is performed.

4.1.31 Speed, design
The maximum rotational speed, measured in revolutions per minute (rpm), for which the fan is designed to operate.

4.1.32 Speed, service
Rotational speed, measured in rpm, at which a rotor operates in its final installation or environment.

4.1.33 Tri-axial set
A set of three measurements taken in three mutually perpendicular directions, normally: horizontal, vertical and axial.

4.1.34 Trim balance
The balance process that makes minor unbalance corrections that may become necessary as a result of the fan assembly or installation process.

4.1.35 Unbalance
A condition of a rotor in which its rotation results in centrifugal forces being applied to the rotor's supporting bearings. Unbalance usually is measured by the product of the mass of the rotor times the distance between its center of gravity and its center of rotation in a plane.

4.1.36 Velocity
In cyclic motion, the time rate of change in displacement.

4.1.37 Vibration
The alternating mechanical motion of an elastic system, the components of which are amplitude, frequency and phase. In general practice, vibration values are reported as:

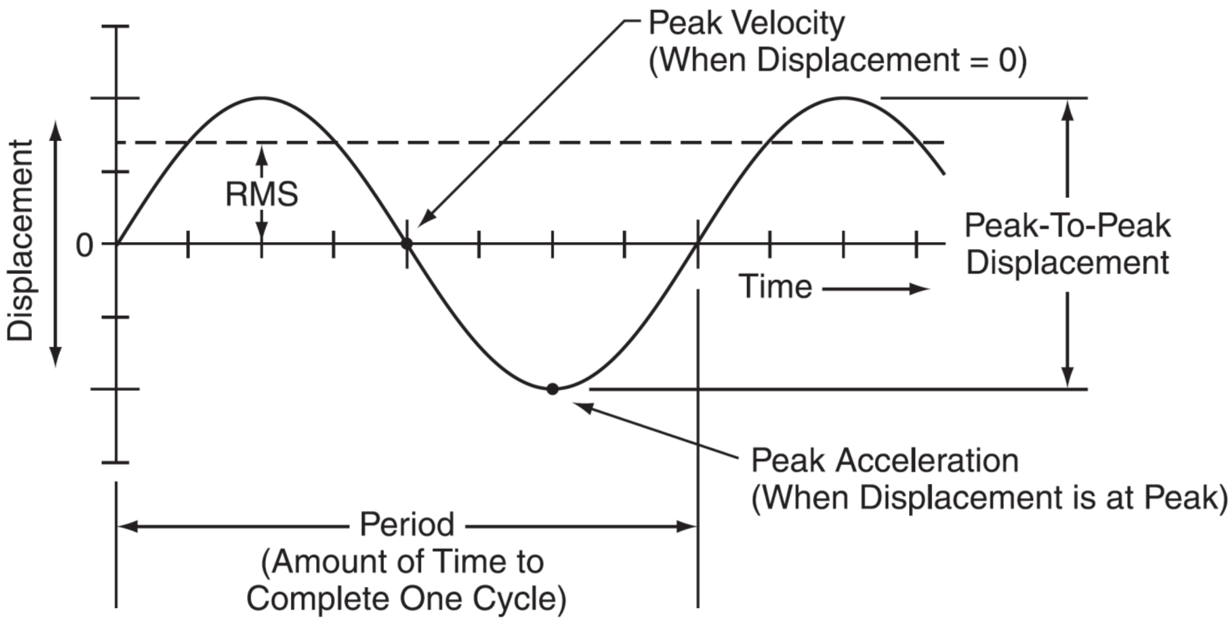
- displacement, peak-to-peak, in mm (mils)
- velocity, peak, in mm/s (in./s)
- acceleration, peak, in g or m/s^2 ($in./s^2$). Standard gravitational acceleration (1 g) = 9.80665 m/s^2 (386.09 $in./s^2$)

4.1.38 Vibration spectrum
A graphical representation of vibration amplitude vs. frequency.

4.1.39 Vibration transducer
A device designed to be attached to a mechanical system for vibration measurement. It produces an electronic signal, that can be displayed or processed, that is proportional to the system's vibration.

4.1.40 Unbalance mass
Mass whose center is at a radial distance from the rotor axis.

4.1.41 Unbalance tolerance
Amount of unbalance that is specified as the maximum, up to which the state of unbalance is considered to be acceptable.



4.2

Symbols

Symbols used in this standard are identified and/or defined where they are presented in pertinent equations.

5. Units of Measure

Units of measure shall be as given in the definitions found in Section 4. In the text and examples, SI (metric) units of measure are given as primary units followed by I-P (inch-pound) units of measure.

6. Application Categories

The design and/or structure of a fan and its intended application are important criteria for categorizing the many types of fans in terms of applicable and meaningful balance quality grades and vibration levels.

Table 6.1 categorizes fans by their application and driver power to arrive at appropriate balance and vibration (BV) application categories.

A fan manufacturer typically will identify the appropriate application category based on the type of fan and its power requirements. A purchaser of a complete fan assembly may be interested in one or more of the following: the balance grade (Table 7.1), factory-tested vibration (Table 8.2) or vibration in situ (Table 8.3). Typically, one BV category will cover the application and driver power considerations. However, a purchaser may request a BV category different than the one listed for the application and driver power considerations. Some may desire a more precise balance quality grade or lower vibration level than is typical for the application.

In most cases, the BV category, balance quality grade and vibration limits must be agreed upon as part of the fan’s contract. In the event no such agreement exists, fans purchased only to comply with this standard shall meet the Table 8.2 vibration limits (assembled fan) or the Table 7.1 residual unbalance requirements (unassembled fan or rotor assembly only).

The purchaser may contract for a particular mounting arrangement to be used for factory testing of an assembled fan to match (as nearly as possible) the planned in-situ mounting at the job site. If no specific BV contract exists, the fan may be mounted either rigidly or flexibly for the test, regardless of the in-situ mounting.

Table 6.1—Fan Application Categories for Balance and Vibration

Application	Examples	Driver Power Limits, kW (hp)	Fan Application Category, BV
Residential	Ceiling fans, attic fans, window air-conditioning unit	≤ 0.15 (0.2) > 0.15 (0.2)	BV-1 BV-2
HVAC and agricultural	Building ventilation and air-conditioning systems; commercial systems	≤ 3.7 (5.0) > 3.7 (5.0)	BV-2 BV-3
Industrial process and power generation etc.	Baghouse, scrubber, mine, conveying, boilers, combustion air, pollution control, wind tunnels	≤ 298 (400) > 298 (400)	BV-3 BV-4
Transportation and marine	Locomotives, trucks, automobiles	≤ 15 (20) > 15 (20)	BV-3 BV-4
Transit and tunnel	Subway emergency ventilation, tunnel fans, garage ventilation	≤ 75 (100) > 75 (100)	BV-3 BV-4
	Tunnel jet fans	ALL	BV-4
Petrochemical process	Hazardous gases, process fans	≤ 37 (50) > 37 (50)	BV-3 BV-4
Computer chip manufacturer	Clean room	ALL	BV-5

7. Balancing

The fan manufacturer is responsible for balancing the fan impeller to acceptable commercial standards. This standard is based on ISO 21940-11:2016. Balancing done in conformance with this standard shall be performed on a highly sensitive, purpose-built balance machine that permits accurate assessment of residual unbalance.

7.1 Balance quality grades

The following balance quality grades apply to fan impellers. A fan manufacturer may include other rotating components (e.g., shaft, coupling, sheave/pulley, etc.) in the rotating assembly being balanced. Additionally, balance of individual components may be required. See references in Annex F for balance requirements for couplings and pulleys.

Table 7.1—Fan Application Categories and Balance Quality Grades

Fan Application Category, BV	Balance Quality Grade for Rigid Rotors/Impeller
BV-1*	G 16
BV-2	G 16
BV-3	G 6.3
BV-4	G 2.5
BV-5	G 1.0
Note: *Category BV-1 may include some extremely small fan rotors weighing less than 227g (8 oz). In such cases, residual unbalance may be difficult to determine accurately. The fabrication process must ensure reasonably equal weight distribution about the axis of rotation.	

7.2 Permissible residual unbalance

G grades as given in Table 7.1 and balance quality grades are constants derived from the product of the relationship $e_{per}\omega$, expressed in mm/s, where e_{per} is the permissible residual specific unbalance, and ω is the angular velocity of the impeller. Thus,

SI units:

$$e_{per} = 1{,}000(G/\omega)$$

$$U_{per} = M\ e_{per} = (30{,}000/\pi)G\ M/N$$

$$\omega = 2\pi N/60$$

Where:
e_{per} = Specific unbalance, μm or (g-mm)/kg
U_{per} = Permissible residual unbalance, (g-mm)
ω = Angular velocity, rad/s
N = Rotor rotational speed, rpm
M = Rotor mass, kg

I-P units:

$$e_{per} = (G/25.4\omega)$$

$$U_{per} = W\ e_{per} = (30/[\pi 25.4])G\ W/N \text{ for } U_{per} \text{ in (lb in.)}$$

$$\omega = 2\pi N/60$$

Where:
e_{per} = Specific unbalance, in. or (lb-in.)/lb
U_{per} = Permissible residual unbalance (moment), (lb-in.)
ω = Angular velocity, rad/s
N = Rotor rotational speed, rpm
W = Rotor weight, lbm

In most applications, the permissible residual unbalance U_{per} in each of two correction planes can be set at $U_{per}/2$. Whenever possible during balancing, a fan impeller should be mounted on the shaft that will be used for the final assembly. If a mandrel is used during balancing, care should be taken to avoid eccentricity due to a loose hub-to-mandrel fit.

Refer to Annex C for graph of e_{per} vs. service speed.

Measurement of the residual unbalance shall be made in accordance with ISO 21940-11:2016.

8. Vibration

8.1 Measurement requirements

Figures 8.1, 8.2, 8.3 and 8.4 illustrate some of the possible locations and directions for taking vibration measurements at each fan bearing. The number and location of measurements to be made during factory or in-situ operation is at the discretion of the fan manufacturer or by agreement with the purchaser. It is recommended that measurements be made at the impeller shaft bearings. Where this is not possible, the pickup shall be mounted in the shortest direct mechanical path between the transducer and the bearing. A transducer shall not be mounted on an unsupported panel, guard or elsewhere on the fan where a solid signal path cannot be obtained. A transducer may be mounted on a fan housing and/or flange where a solid signal path is obtained between a bearing and the measurement point.

A horizontal measurement shall always be made in a radial direction and perpendicular to the axis of rotation. A vertical measurement reading shall always be made perpendicular to the axis of rotation and perpendicular to a horizontal reading. An axial measurement shall always be made parallel to the shaft (rotor) axis of rotation.

Where the fan shaft is not horizontal, ‘vertical’ and ‘horizontal’ shall be two radial directions, perpendicular to each other.

8.1.1 Seismic measurements

All vibration values in this standard are seismic measurements that represent motion of each bearing housing.

Observations shall include measurements made with accelerometer or velocity-type instruments. Particular attention should be given to ensure that the vibration-sensing transducer is mounted correctly without looseness, rocking or resonance.

The size and weight of the transducer and its mounting system should not be so large that its presence significantly affects the vibration response characteristics of the fan. Variables associated with transducer mounting and variations in instrument calibration can lead to measurement variations of ±10%.

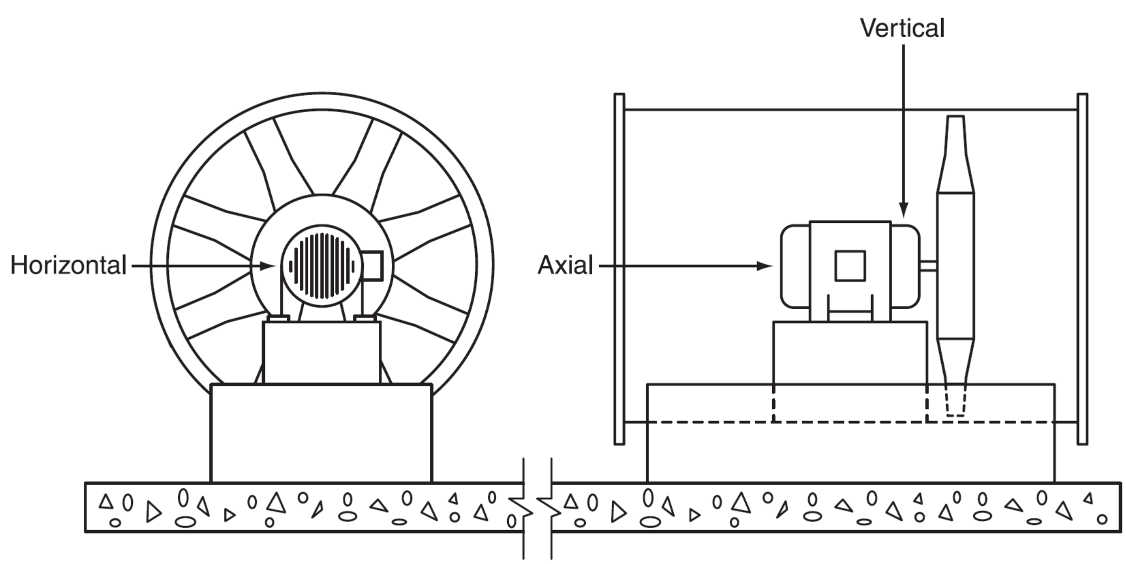


Figure 8.1—Transducer Mounting Direction (Locations): Axial Fan, Horizontal Airflow

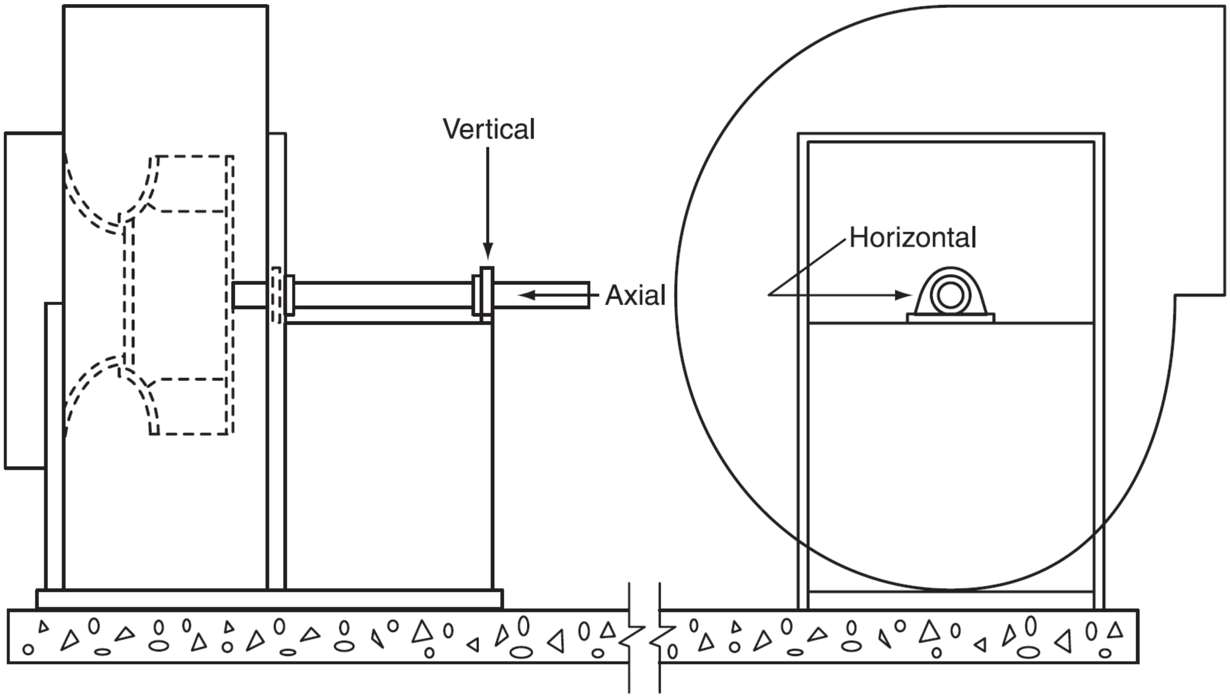


Figure 8.2—Transducer Mounting Direction (Locations): Single-Width Centrifugal Fan

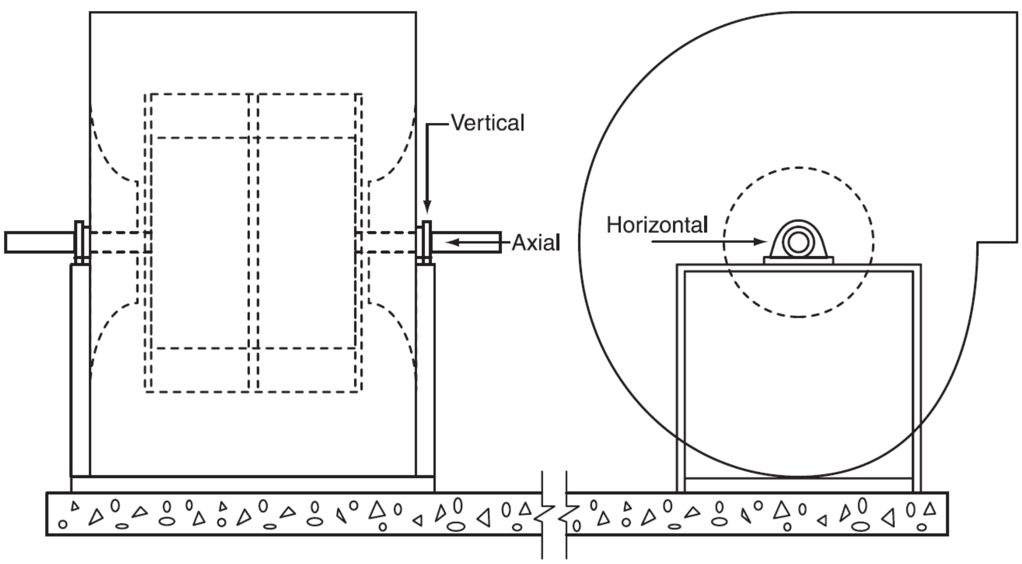


Figure 8.3—Transducer Mounting Direction (Locations): Double-Width Centrifugal Fan

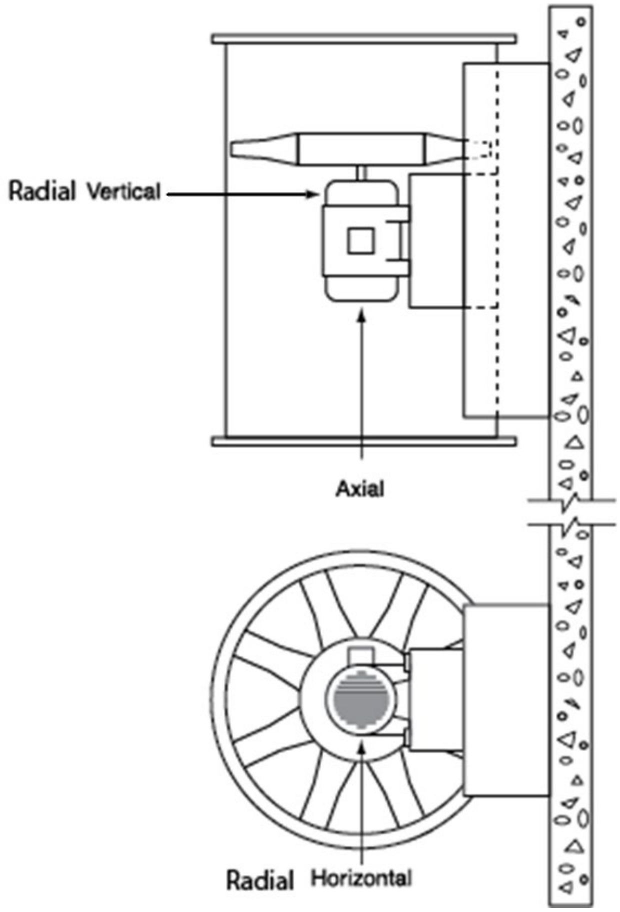


Figure 8.4—Transducer Mounting Direction (Locations): Axial Fan, Vertical Airflow

8.1.2 Displacement measurements

The following discussion applies to the measurement of shaft displacement within a sleeve-bearing oil film by means of proximity probe systems.

Such systems measure the relative motion between the surface of the rotating shaft and the bearing housing. Clearly, the allowable displacement amplitude must be limited to a value less than the bearing's diametric clearance. This internal clearance varies as a function of the bearing size, radial/axial loading, bearing type and axis of interest (i.e., some designs have an elliptical bore with larger clearance in the horizontal axis than in the vertical axis). Therefore, it is not the intent of this standard to establish discrete shaft displacement limits for all bearings and fan applications. However, the following guideline is recommended for shaft displacement limits. The values shown in Table 8.1 are percentages of the total available clearance within the bearing in each axis.

Table 8.1—Maximum Recommended Displacements

Condition	Maximum Recommended Displacement as a Percent of Available Diametral Clearance (Any Axis)
Startup/ satisfactory	<+25%*
Alarm level	50%
Shutdown level	70%
*Note: Contact bearing supplier to obtain the available diametral and axial clearances within the particular sleeve bearings being used.	

Caution should be used when relying solely on proximity probes for vibration alarming. It is possible for the proximity probe support and the fan shaft to move in phase so no relative motion is measured even though high vibration levels relative to a fixed frame of reference exist. Because of this, when proximity probes are used, seismic vibration pickups also are recommended.

This measurement involves the apparent motion of the shaft surface. Measurements are affected not only by shaft vibration but also any mechanical run-out of the shaft if it is bent or out-of-round. The magnetic/electrical properties of the shaft material at the measurement point also affect the electrical run-out of the shaft as measured by a proximity probe. The combined mechanical and electrical probe-track run-out of the shaft material at the measurement point should not exceed 0.0127 mm (0.0005 in.) peak-to-peak, or 25% of the startup/satisfactory vibration displacement value, whichever is greater. This run-out should be determined during a slow-roll speed test (100 to 400 rpm), where the unbalance forces on the rotor are negligible. Special shaft preparation may be required to achieve satisfactory run-out measurement. Proximity probes should be mounted directly in the bearing housing whenever possible.

Example: Recommended guidelines for a normal 152 mm (6 in.) diameter sleeve bearing with a horizontal internal clearance of 0.33 mm (0.013 in.):

<u>Limits of Relative Shaft Vibration</u>

Startup/satisfactory = (0.25 × 0.33 mm) = 0.0825 mm, pk-pk (SI)
= (0.25 × 0.013 in.) = 0.0033 in. or 3.3 mils, pk-pk (I-P)

Alarm = (0.50 × 0.33 mm) = 0.165 mm, pk-pk (SI)
= (0.50 × 0.013 in.) = 0.0065 in. or 6.5 mils, pk-pk (I-P)

Shutdown = (0.70 × 0.33 mm) = 0.231 mm, pk-pk (SI)
= (0.70 × 0.013 in.) = 0.0091 in. or 9 mils, pk-pk (I-P)

Combined mechanical and electrical run-out of the shaft at the point of vibration measurement:

a. 0.0127 mm (SI)

0.0005 in. (I-P)

b. 0.25 × 0.0825 mm = 0.0206 mm (SI)

0.25 × 0.0033 in. = 0.0008 in., or 0.8 mils (I-P)

Choose the greater of the two values (a or b): 0.0206 mm (0.8 mils)

8.2 Fan support system

Fan installations are classified for vibration severity according to their support flexibility. To be classified as rigidly supported, the fan and support system should have a fundamental (lowest) natural frequency above the running speed. To be classified as flexibly supported, the fan and support system should have a fundamental frequency below the running speed. Generally, a large, well-designed concrete foundation will result in rigid support, whereas a fan mounted on vibration isolators will be classified as flexible support.

Fans mounted on steelwork can be in either category, depending on the structural design. In case of doubt, analysis or tests should be performed to determine the fundamental natural frequency. Note that in some cases, a fan could be classified as rigidly supported in one measurement direction and flexibly supported in another (AMCA Publication 801).

8.3 Factory tests

The vibration limit values in Table 8.2 apply to an assembled fan tested in the manufacturer's factory. (Values shown are velocity values, filter-in at the fan rotational speed during the factory test.)

Table 8.2—Vibration Limits for Factory Tests

Fan Application Category, BV	Rigidly Mounted mm/s (in./s)		Flexibly Mounted mm/s (in./s)	
	Peak	RMS	Peak	RMS
BV-1	12.7 (0.50)	9.0 (0.35)	15.2 (0.60)	11.2 (0.44)
BV-2	5.1 (0.20)	3.5 (0.14)	7.6 (0.30)	5.6 (0.22)
BV-3	3.8 (0.15)	2.8 (0.11)	5.1 (0.20)	3.5 (0.14)
BV-4	2.5 (0.10)	1.8 (0.07)	3.8 (0.15)	2.8 (0.11)
BV-5	2.0 (0.08)	1.4 (0.06)	2.5 (0.10)	1.8 (0.07)
Note: Peak values are widely used in North America and are made up of several sinusoidal waveforms that do not necessarily have an exact match with RMS values. They also may depend to some extent on the instrument used.				

8.4 Vibration limits for operation in situ

The in-situ vibration level of a fan is not solely dependent upon the balance quality grade. Installation factors and the mass and stiffness of the supporting system will influence the in-situ vibration level (AMCA Publication 202). Therefore, in-situ fan vibration level is not the responsibility of the fan manufacturer unless specified in the purchase contract.

The vibration velocity levels in Table 8.3 provide guidelines for acceptable operation of fans in various application categories. The velocity values shown are for filter-out measurements taken at the bearing housings as shown in Figures 8.1 through 8.4.

The vibration velocity of a newly commissioned fan should be at or below the startup level. As fan operation increases with time, the fan vibration level is expected to increase due to wear and other accumulated effects. In general, an increase in vibration is reasonable as long as the level does not reach the alarm value for the category.

If the severity of vibration velocity increases to the alarm level, action should be initiated immediately to determine the cause of the increase as well as to correct the condition. Operation at this condition should be monitored carefully and limited to the minimum time required to develop a corrective action program.

If the vibration velocity increases to the shutdown level, corrective action should be taken immediately, or the fan should be shut down.

Failure to reduce the shutdown level vibration velocity to the acceptable recommended level could lead to bearing failure, cracking of rotor parts and fan housing structural welds and, ultimately, catastrophic failure.

Historical data is an important factor when considering the vibration severity of any fan installation. A sudden increase in vibration velocity level may indicate the need for prompt inspection or maintenance. Transitory changes in vibration level that result from relubrication, maintenance or process upsets should not be used for evaluating the equipment's condition.

Table 8.3—Vibration Limits for In-situ Tests
The values in this table represent the overall vibration value with a minimum frequency range of 10-1,000 Hz for both calculated FFT and analog measurements.

Condition	Fan Application Category	Rigidly Mounted mm/s (in./s)		Flexibly Mounted mm/s (in./s)	
		Peak	RMS	Peak	RMS
Startup	BV-1	14.0 (0.55)	10 (0.39)	15.2 (0.60)	11.2 (0.44)
	BV-2	7.6 (0.30)	5.6 (0.22)	12.7 (0.50)	9.0 (0.35)
	BV-3	6.4 (0.25)	4.5 (0.18)	8.8 (0.35)	6.3 (0.25)
	BV-4	4.1 (0.16)	2.8 (0.11)	6.4 (0.25)	4.5 (0.18)
	BV-5	2.5 (0.10)	1.8 (0.07)	4.1 (0.16)	2.8 (0.11)
Alarm	BV-1	15.2 (0.60)	10.6 (0.42)	19.1 (0.75)	14.0 (0.55)
	BV-2	12.7 (0.50)	9.0 (0.35)	19.1 (0.75)	14.0 (0.5)
	BV-3	10.2 (0.40)	7.1 (0.28)	16.5 (0.65)	11.8 (0.28)
	BV-4	6.4 (0.25)	4.5 (0.18)	10.2 (0.40)	7.1 (0.28)
	BV-5	5.7 (0.20)	4.0 (0.16)	7.6 (0.30)	5.6 (0.22)
Shutdown	BV-1	NOTE 1	NOTE 1	NOTE 1	NOTE 1
	BV-2	NOTE 1	NOTE 1	NOTE 1	NOTE 1
	BV-3	12.7 (0.50)	9.0 (0.35)	17.8 (0.70)	12.5 (0.49)
	BV-4	10.2 (0.40)	7.1 (0.28)	15.2 (0.60)	11.2 (0.44)
	BV-5	7.6 (0.30)	5.6 (0.22)	10.2 (0.40)	7.1 (0.28)

Notes:
1. Shutdown levels for fans in Fan Application Grades BV-1 and BV-2 must be established based on historical data.
2. Peak values are widely used in North America and are made up of a number of sinusoidal waveforms. The peak values do not necessarily have an exact match with RMS values and also depend on the instrument used to some extent.

9. Other Rotating Components

Accessory rotating components that could affect fan vibration levels include drive sheaves, belts, couplings and motor/driver devices. When a fan is ordered from the fan manufacturer bare (i.e., no drive or motor supplied or installed by the fan manufacturer), it is not always practical or possible for the manufacturer to perform a final assembly test run, or factory test, to check vibration levels. Therefore, though the impeller may have been balanced by the fan manufacturer, the customer is not assured of a smooth-running assembled fan until the drive and/or driver are connected to the fan shaft and the unit is run and tested to determine the startup vibration levels. It is common for assembled fans to require trim balancing to reduce vibration to acceptable startup vibration levels. The final assembly test run is recommended for all new BV-3, BV-4 and BV-5 fan installations before commissioning for service. This establishes a baseline for future predictive maintenance efforts.

The fan manufacturer cannot be responsible for the effects of vibration on drive components added after the factory test run.

Additional information on the balance quality or component vibration may be found in the references given in Annex F.

10. Documentation

10.1 Balance

Written certification of the balance achieved for an individual rotor shall be provided upon request when negotiated. In such cases, it is recommended that the following information be included in the balance certification report:

- Balance machine manufacturer and model number
- Specify whether rotor was overhung or between centers
- Single or two-plane balance method
- Mass of rotating assembly
- Residual unbalance in each correction plane
- Allowable residual unbalance in each correction plane for the balance quality grade
- Applicable balance quality grade
- Pass or fail rotor balance
- Certificate of balance, if required

In some cases, keeping a written record of an individual rotor is impractical. In such cases, the fan manufacturer's records, or standard operating procedures, shall be sufficient evidence of balance achievement.

10.2 Vibration

Written certification of the vibration velocity level achieved for a fan shall be provided upon request when negotiated. In such cases, it is recommended that the following information be included in the vibration certification report:

- Manufacturer and model number of vibration instrumentation
- Fan operating point
- Fan rotational speed
- Flexible or rigid mount
- Description of measurements:
    - method of transducer attachment to measurement location, position and axis
    - units of measure used and reference levels
    - frequency, bandwidth and whether vibration analyzer was tuned to filter-in or filter-out
- Allowable vibration velocity levels
- Measured vibration velocity levels
- Pass or fail vibration velocity levels
- Certificate of vibration velocity, if required

In some cases, keeping a written record of an individual rotor is impractical. In such cases, the fan manufacturer's records, or standard operating procedures, shall be sufficient evidence of balance achievement.

Annex A
SI/I-P Conversion Table (Informative)

Table A.1—Conversion Factors Between SI and I-P Systems

Quantity	I-P to SI	SI to I-P
Length	(ft) 0.3048 = m	(m) 3.2808 = ft
Mass	(lbm) 0.4536 = kg	(kg) 2.2046 = lbm
Time	The unit of time is the second in both systems	
Velocity	(ft/s) 0.3048 = m/s (ft/min) 0.00508 = m/s	(m/s) 3.2808 = ft/s (m/s) 196.85 = ft/min
Acceleration	(in./s^2) 0.0254 = m/s^2	(m/s^2) 39.370 = in/s/^{2}
Area	(ft^2) 0.09290 = m^2	(m^2) 10.764 = ft^2
Volume flow rate	(cfm) 0.000471948 = m^3/s	(m^3/s) 2118.88 = cfm
Power	(BHP) 746 = W (BHP) 0.746 = kW	(W)/746 = BHP (kW)/0.746 = BHP

Annex B
Relationships (Informative)

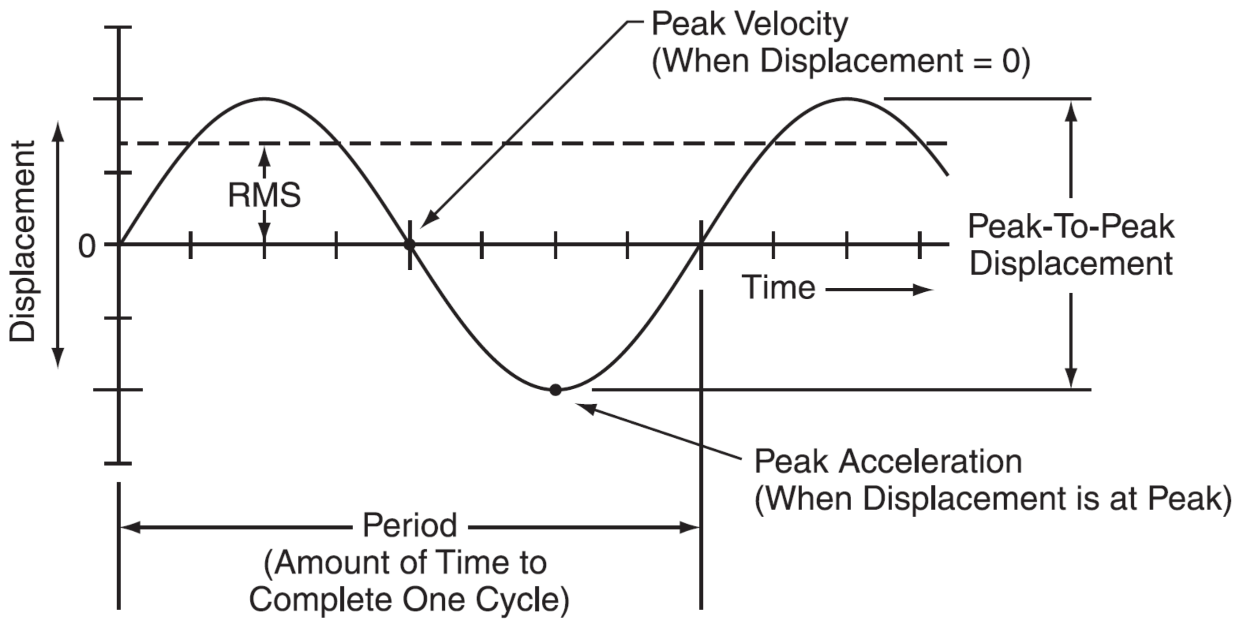


Figure B.1—Relationships of Vibration Displacement, Velocity and Acceleration for Sinusoidal Motion

Generally, there is no simple relationship among broadband acceleration, velocity and displacement, nor is there one among peak (pk), peak-to-peak (pk-pk), root-mean-square (RMS) and average values of vibration. However, when the vibration is totally or predominantly at a single frequency (e.g., due to residual unbalance) or the filter-in reading is measured, the following relationships exist independent of the unit system involved:

$$A_{rms} = \frac{A_{pk}}{\sqrt{2}}$$

$$V_{rms} = \frac{V_{pk}}{\sqrt{2}}$$

The following relationships exist and are dependent upon the units of measure used:

For SI units of measure

Displacement	D_{pkpk}	mm
Velocity	V_{pk}	mm/s
Acceleration	A_{pk}	gs (1 g = 9.80665 m/s^2)
Frequency	F	Hz

Relationship equations

$$F = N/60$$

$$V_{pk} = \pi F D_{pkpk}$$

$$A_{pk} = \frac{2(\pi F)^2 D_{pkpk}}{(9.80665)(1000)} = \frac{F^2 D_{pkpk}}{496.8}$$

$$D_{pkpk} = \frac{V_{pk}}{\pi F}$$

$$D_{pkpk} = \frac{(1000)(9.80665)A_{pk}}{2(\pi F)^2} = \frac{496.8 A_{pk}}{F^2}$$

$$V_{pk} = \frac{(1000)(9.80665)A_{pk}}{2\pi F} = \frac{1561 A_{pk}}{F}$$

$$A_{pk} = \frac{2\pi F V_{pk}}{(1000)(9.80665)} = \frac{F V_{pk}}{1561}$$

Example: D_{pkpk} = 0.10 mm at N = 1800 rpm

$$F = 1800/60 = 30 \text{ Hz}$$

$$V_{pk} = \pi(30)(0.10) = 9.42 \text{ mm/s}$$

$$A_{pk} = \frac{(30)^2(0.10)}{496.8} = 0.181 \text{ g's}$$

$$D_{pkpk} = \frac{9.42}{\pi(30)} = 0.10 \text{ mm}$$

$$D_{pkpk} = \frac{(496.8)(0.181)}{(30)^2} = 0.10 \text{ mm}$$

$$V_{pk} = \frac{(1561)(0.181)}{30} = 9.42 \text{ mm/s}$$

$$A_{pk} = \frac{(30)(9.42)}{1561} = 0.181 \text{ g's}$$

For filter-in readings, the following relationships exist and are dependent upon the units of measure used:

For I-P units of measure

Displacement	D_{pkpk}	mils (1 mil = 0.001 in.)
Velocity	V_{pk}	in./s
Acceleration	A_{pk}	g's (1 g = 386.09 in./s^2)
Frequency	N	rev/min (rpm)

Relationship equations

$$V_{pk} = \frac{\pi N D_{pkpk}}{(60)(1000)} = \frac{N D_{pkpk}}{19{,}100}$$

$$A_{pk} = \frac{2(\pi N)^2 D_{pkpk}}{(60)^2(1000)(386.09)} = (1.42 \times 10^{-8}) N^2 D_{pkpk}$$

$$D_{pkpk} = \frac{(60)(1000)V_{pk}}{\pi N} = \frac{(19{,}100)V_{pk}}{N}$$

$$D_{pkpk} = \frac{(60)(1000)(386.09)A_{pk}}{2(\pi N)^2} = \frac{A_{pk}}{(1.42\ x\ 10^{-8})N^2}$$

$$V_{pk} = \frac{(60)(386.09)A_{pk}}{2\pi N} = \frac{(3687)A_{pk}}{N}$$

$$A_{pk} = \frac{2\pi F V_{pk}}{(60)(386.09)} = \frac{N V_{pk}}{(3687)}$$

Example: D_{pkpk} = 2.4 mils at N = 1780 rpm

$$V_{pk} = \frac{(1780)(2.4)}{(19{,}100)} = 0.224 \text{ in./s}$$

$$A_{pk} = (1.42 \times 10^{-8})(1780)^2(2.4) = 0.108 \text{ g's}$$

$$D_{pkpk} = \frac{(19{,}100)(0.224)}{(1780)} = 2.4 \text{ mils}$$

$$D_{pkpk} = \frac{0.108}{(1.42x10^{-8})(1780)^2} = 2.4 \text{ mils}$$

$$V_{pk} = \frac{(3687)(0.108)}{(1780)} = 0.224 \text{ in./s}$$

$$A_{pk} = \frac{(1780)(0.224)}{3687} = 0.108 \text{ g's}$$

Annex C
Maximum Permissible Residual Imbalance (Informative)

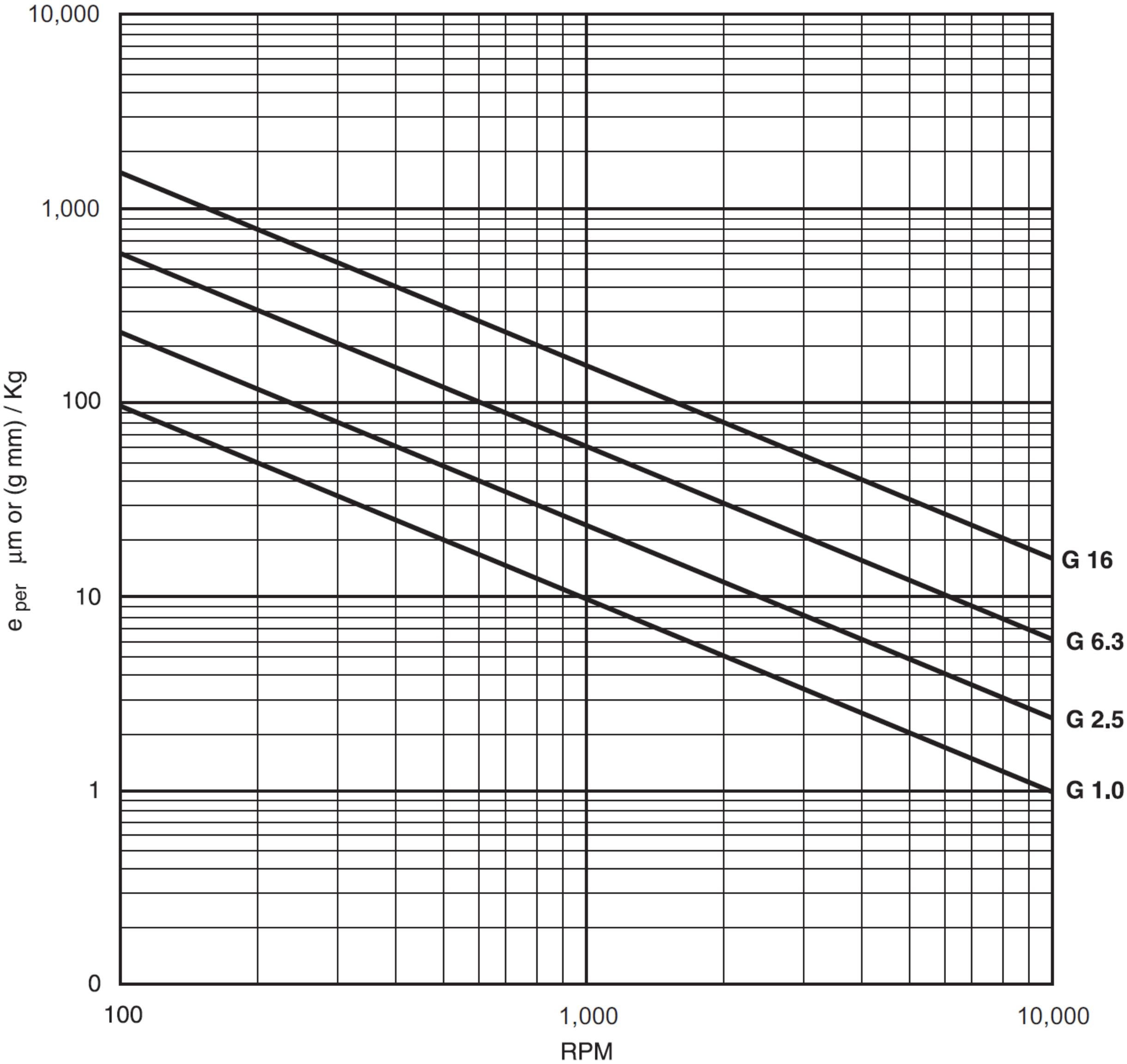


Figure C.1—Maximum Permissible Residual Unbalance (SI)

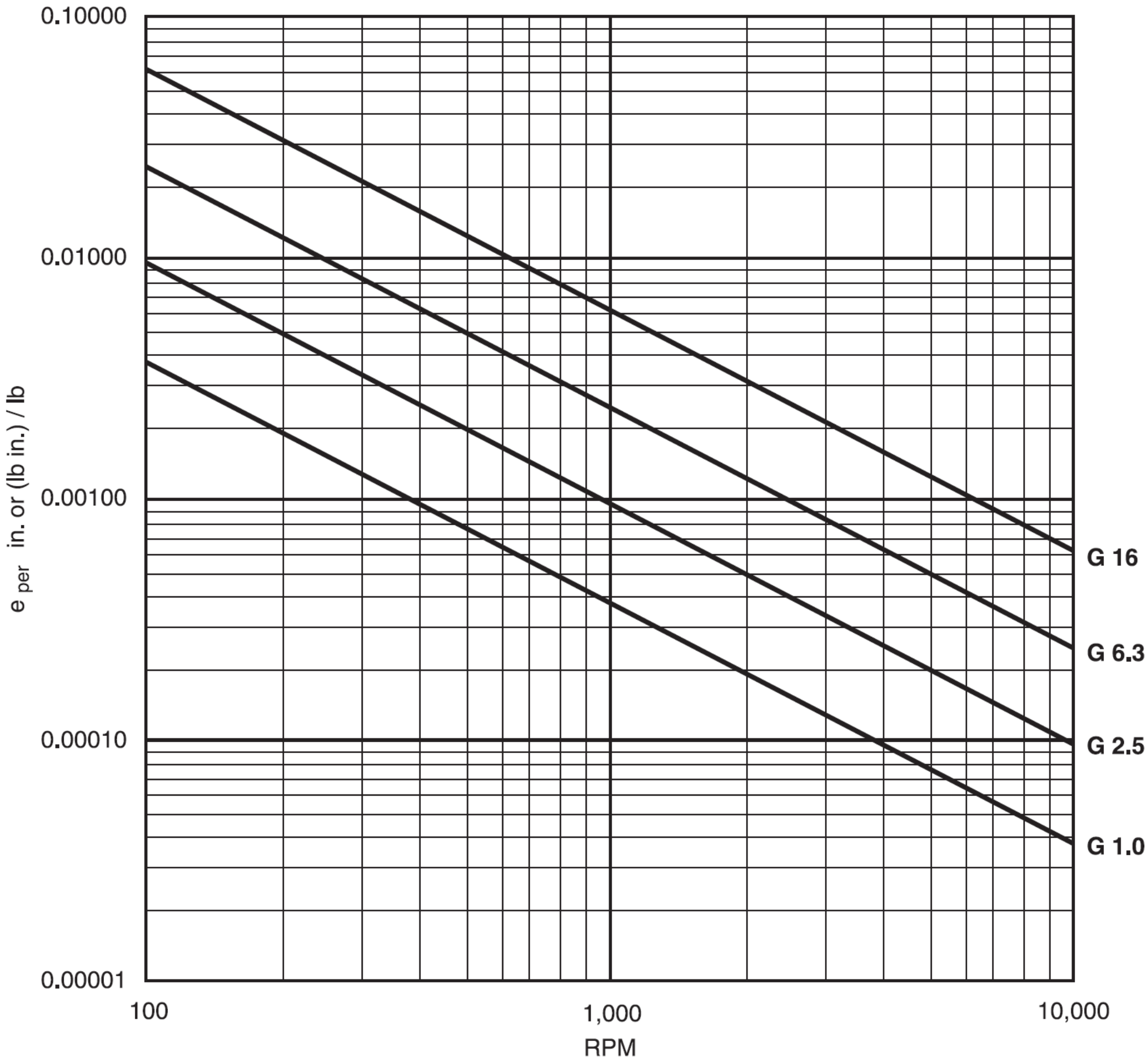


Figure C.2—Maximum Permissible Residual Unbalance (I-P)

Annex D
Instruments and Calibration (Informative)

D.1 Instruments

Instruments and balancing machines used shall meet the requirements of the task and be within current calibration. The calibration period and methods used for an instrument should be that which are recommended by the instrument manufacturer or should follow procedures made in ISO 21940-21:2012. Instruments shall be in good condition and suitable for their intended function for the complete duration of the test. A portable instrument battery change made during the test may invalidate the test results.

Personnel operating instruments shall be familiar with them and possess enough experience to detect a possible malfunction or degradation of instrument performance. When an instrument requires corrective measures or calibration, it shall be removed from service until corrective action is taken.

D.2 Calibration

All instruments shall be calibrated against a known standard. The complexity of the calibration may vary from a physical inspection to a complete calibration traceable to the National Institute of Standards and Technology. The manufacturer's recommended calibration method and frequency should be followed.

Annex E
Digital Overall Vibration Calculation (Informative)

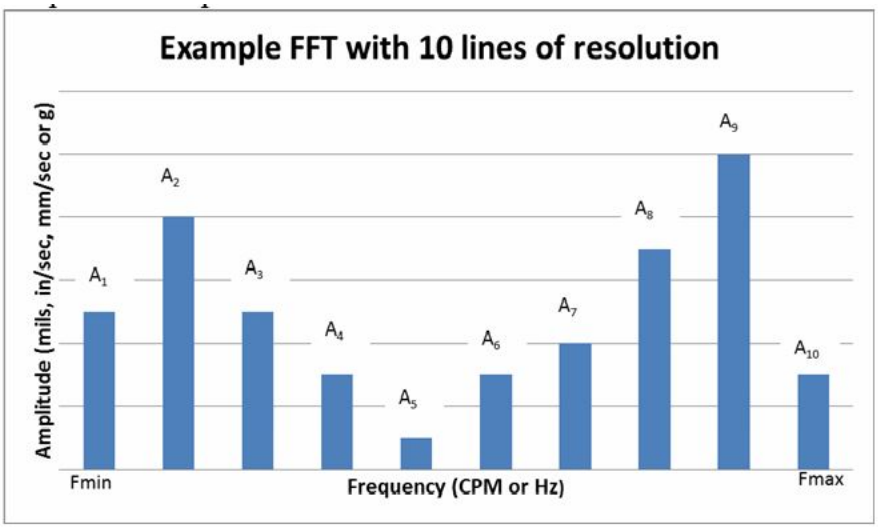
The digital overall vibration is the total sum of all the vibration measured by the transducer within the specified frequency band ranging from the minimum frequency, Fmin, to the maximum frequency, Fmax. By taking the amplitude of each frequency bin (or lines of resolution), squaring it and adding all the squared amplitudes together, then taking the squared root of that sum and dividing by the square root of a noise factor (Equation 1), the result is the digital overall vibration for that frequency spectrum.

$$\text{Overall Vibration} = \frac{\sqrt{\sum_{i=1}^{n} A_i^2}}{\sqrt{Nf}}$$

Equation 1

Today, most vibration analyzers or computers automatically will calculate the digital overall vibration for the numerous FFT lines of resolution. A noise factor using the Hanning window is typical, where Nf = 1.5. There are other less commonly used window options, such as uniform window, Nf = 1.0, and flat-top window, Nf = 3.2-3.8. Understanding which noise factor window is used on a given analyzer may be important if comparing results with different makes, models settings or acceptance criteria.

Example graph:



$$\text{Overall Vibration} = \frac{\sqrt{\sum_{i=1}^{n} A_i^2}}{\sqrt{Nf}} = \frac{\sqrt{A_1^2 \quad + \quad A_2^2 \quad + \ldots \quad + \quad A_{10}^2}}{\sqrt{1.5}}$$

Where:

n = Number of lines of resolution or frequency bins
Nf = Noise bandwidth for window chosen; 1.5 for Hanning window
A_i = Amplitude of frequency bin of interest
Fmin = Minimum frequency included in spectrum
Fmax = Maximum frequency included in spectrum

Annex F
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Air Movement and Control Association International

AMCA Corporate Headquarters
30 W. University Drive, Arlington Heights, IL 60004-1893, USA
communications@amca.org ▪ Ph: +1-847-394-0150 ▪ www.amca.org