Section I
General Standards Applying to All Machines
Part 7
Mechanical Vibration—Measurement, Evaluation, and Limits

7.1 Scope

This standard is applicable to direct-current machines tested with direct-current power and to polyphase alternating-current machines tested with sinusoidal power, in frame sizes 42 and larger and at rated power up to 100,000 HP or 75 MW, at nominal speeds up to and including 3600 rev/min.

For vertical and flange-mounting machines, this standard is applicable only to those machines that are tested in the intended orientation.

This standard is not applicable to single-bearing machines, machines mounted in situ, single-phase machines, three-phase machines operated on single-phase systems, vertical water power generators, permanent magnet generators, or machines coupled to prime movers or driven loads.

Note: For machines measured in situ, refer to ISO 10816-3.

7.2 Object

This standard establishes the test and measurement conditions of, and fixes the limits for, the level of vibration of an electrical machine, when measurements are made on the machine alone in a test area under properly controlled conditions. Measurement quantities are the vibration levels (velocity, displacement, and/or acceleration) at the machine bearing housings and the shaft vibration relative to the bearing housings within or near the machine bearings. Shaft vibration measurements are recommended only for machines with sleeve bearings and speeds equal to or greater than 1000 rev/min and shall be the subject of prior agreement between manufacturer and user with respect to the necessary provisions for the installation of the measurement probes.

7.3 References

Referenced documents used in this Part are ISO 2954, ISO 20816-1, ISO 10816-3, ISO 10817-1, ISO 21940-32, IEC 60034-7, and IEC 60034-14.

7.4 Measurement Quantity

7.4.1 Bearing Housing Vibration

The criterion adopted for bearing housing vibration is the peak value of the overall (unfiltered) vibration velocity in inches per second. The greatest value measured at the prescribed measuring points (see 7.7.2) characterizes the vibration of the machine.

7.4.2 Relative Shaft Vibration

The criterion adopted for relative shaft vibration (relative to the bearing housing) is the peak-to-peak vibratory displacement (S_{p-p}) in mils in the direction of measurement (see ISO 20816-1).

7.5 Measurement Equipment

The measurement equipment shall be capable of measuring broadband rms vibration with flat response over a frequency range of at least 10 Hz to 1000 Hz, in accordance with the requirements of ISO 2954. However, for machines with speeds below 600 rpm, the lower limit of the flat response frequency range shall not be greater than 2 Hz.

Measurement equipment for relative shaft vibration measurements shall comply with the requirements in ISO 10817-1.

Equipment used to measure vibration shall be accurate to within ±10% of the allowable limit for the vibration being measured.

Note 1: Multi-directional sensors do not provide proper vibration measurement in all directions when mounted in only one location.

Note 2: Axial vibration measurement may not be possible without disassembly on both ends. If a machine has thrust bearings, this measurement should be per agreement between supplier and customer.

7.6 Machine Mounting

7.6.1 General

Evaluation of vibration of rotating electrical machines requires measurement of the machines under properly determined test conditions to enable reproducible tests and to provide comparable measurements. The vibration of an electrical machine is closely linked with the mounting of the machine. The choice of the mounting method will be made by the manufacturer. Typically, machines with shaft heights of 11 inches or less use resilient mounting. For machines with speeds lower than 600 rpm, resilient mounting is not practical.

Note: The shaft height of a machine without feet, or a machine with raised feet, or any vertical machine, is to be taken as the shaft height of a machine in the same basic frame, but of the horizontal shaft foot-mounting type.

7.6.2 Resilient Mounting/Free Suspension

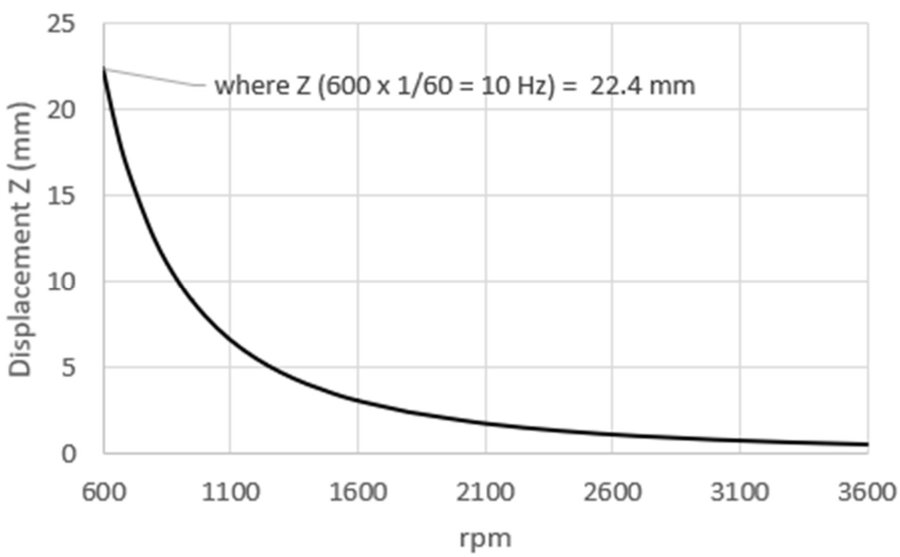
This condition is achieved by suspending the machine from a spring or by mounting on an elastic support (springs, rubber, etc.).

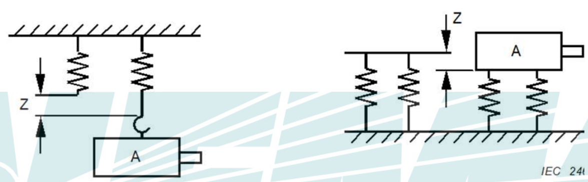
The highest natural oscillation frequency (f_{no}) of the suspension system and machine shall be less than 1/3 of the frequency f_1 corresponding to the speed of the machine under test, as defined in 7.7.3.3. Based on the mass of the machine being tested, the necessary elasticity of the suspension system as a function of nominal speed from 600 rpm to 3600 rpm can be determined from a curve such as that given in Figure 7-1 from the appropriate value of *a* in the equation below for *Z*. For speeds lower than 600 rpm, measurements in free suspension are not practical. For speeds greater than 3600 rpm, the static displacement *Z* should be not less than the value for 3600 rpm.

The curve in Figure 7-1 presents, for the specific case where *a* in the equation below is equal to 3, the minimum displacement limit for vertical rigid body natural oscillation frequency, which is usually the highest rigid body natural frequency. Static displacement *Z* is expressed as:

$$Z = \frac{a^2 g}{\left(2\pi \frac{n}{60}\right)^2} \ x\ 1000 \qquad , a = \frac{f_1}{f_{no}}; \ \ a \geq 3$$

where *Z* is the displacement in millimeters, *n* is the nominal speed in units of rpm, and *g* is the acceleration of gravity (9.82 m/s²).





Key

A machine under test

Z displacement

Note: To reduce the influence of the mass and the moments of inertia of the suspension system on the vibration level, the effective mass of the elastic support should be not greater than 1/10 of that of the machine.

Figure 7-1
Minimum Elastic Displacement as a Function of Nominal Speed
(based on Figure 1 of IEC 60034-14: 2018)[1]
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7.6.3 Rigid Mounting

7.6.3.1 Horizontal Machines

The machine under test shall be bolted or clamped to a foundation that meets the requirements of 7.6.3.3 or 7.6.3.4 using at least 4 of the bolt hole positions that correspond with the frame designation.

Either of the two mounting methods described in 7.6.3.3 and 7.6.3.4 may be chosen by the manufacturer.

7.6.3.2 Vertical Machines

Vertical machines shall be mounted onto a solid rectangular or circular steel plate, which may be part of a base or securely fastened to a base. This plate shall have a bore hole in the center for the shaft extension, a machined surface for the flange of the electrical machine being measured, and holes provided for fasteners or clamps. The steel plate thickness shall be at least three times greater than the machine flange thickness. Five times is preferable.

The connection of the flange of the machine to the plate shall use a number of fasteners or clamps equal to the number of holes in the motor flange unless otherwise specified by the manufacturer. If the above method of mounting is not reasonable, other arrangements can be per agreement between supplier and customer.

The base shall be bolted or clamped firmly to the foundation or floor in order to safely prevent tilting and meet the requirements of 7.6.3.3 or 7.6.3.4.

Either one of the two mounting methods described in 7.6.3.3 and 7.6.3.4 may be chosen by the manufacturer.

7.6.3.3 Rigid Mounting of Horizontal and Vertical Machines on Massive Foundation

One indication of a massive foundation is when the vibration velocity measured in any direction at the machine feet (or at the base frame near the bearing pedestals or stator feet) does not exceed 30% of the maximum velocity, which is measured at the adjacent bearing housing in the same measurement direction.

Note 1: This requirement ensures that the horizontal and vertical natural frequencies of the complete test arrangement do not coincide with possible forcing frequencies within the range of any of the following:

a) ±10% of the rotational frequency of the machine;
b) ±5% of twice the rotational frequency; or
c) ±5% of once and twice the electrical line frequency.

Note 2: The rigidity of a foundation is a relative quantity. It should be compared 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. One indication that a foundation is massive is if the vibration amplitudes of the foundation (in any direction) near the machine feet or base frame are less than 30% of the amplitudes that could be measured at the adjacent bearing housing in any direction. The ratio of foot to bearing vibration velocities is valid for once per revolution vibration and the vibration at twice the line frequency (if the latter is being evaluated).

Note 3: During a shop running test of the assembled machine, vibration measurements shall be made with the machine properly shimmed and securely fastened to a massive foundation or test floor stand. Elastic mounts are not permitted.

Note 4: If the machine is supported in the field by a structure other than a massive foundation, it may be necessary to perform a system dynamic analysis to make the necessary changes to the foundation dynamic stiffness.

7.6.3.4 Rigid Mounting of Horizontal and Vertical Machines on Test Floor Stand

This condition is achieved by mounting the machine on an adequately rigid test foundation free of resonances at forcing frequencies (see Note 1 of 7.6.3.3).

Note 1: This mounting is the most used in manufacturers' test labs.

Note 2: During the shop running test of the assembled machine, vibration measurements shall be made with the machine properly shimmed and securely fastened to a test floor stand. Elastic mounts are not permitted.

7.6.4 Active Environment Determination

The support systems mentioned in 7.6.2 and 7.6.3 are considered passive, admitting insignificant external disturbances to the machine. If the vibration with the machine stationary exceeds 25% of the value when the machine is running, then an active environment is said to exist. Vibration criteria for active support systems are not given in this Part.

7.7 Conditions of Measurement

7.7.1 Shaft Key

For the balancing and measurement of vibration on machines provided with a shaft extension keyway, the keyway shall contain a half key.

For more specific details on key design, see ISO 21940-32.

7.7.2 Measurement Points for Vibration

7.7.2.1 Bearing Housing

The location of the measurement points and directions to which the levels of vibration severity apply are shown in Figure 7-2 for machines with end-shield bearings and in Figure 7-4 for machines with pedestal bearings. Figure 7-3 applies to those machines where measurement positions according to Figure 7-2 are not possible without disassembly of parts, or where no hub exists. Measurement according to Figure 7-3 shall be on the frame as close to the bearing housing as possible.

Multi-directional vibration sensors shall not be used.

7.7.2.2 Shaft

Non-contacting transducers, if used, shall be installed inside the bearing, measuring directly the relative shaft journal displacement, or near the bearing shell when mounting inside is not practical. The preferred radial positions are as indicated in Figure 7-5.

7.7.3 Operating Conditions

7.7.3.1 General

For machines that are bi-directional, the vibration limits apply for both directions of rotation, but need to be measured in only one direction.

Measurement of the vibration shall be made with the machine at no load and uncoupled.

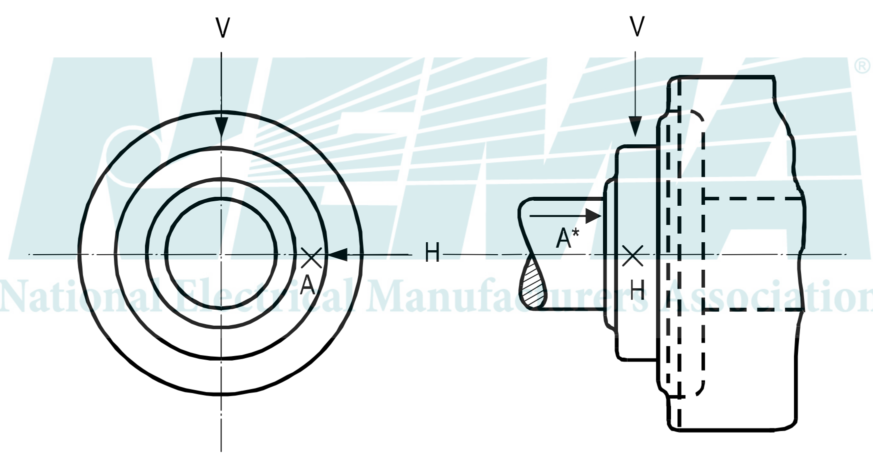
7.7.3.2 Power Supply

Alternating-current machines shall be run at rated frequency and rated voltage with a virtually sinusoidal wave form. The power supply shall provide balanced phase voltages closely approaching a sinusoidal waveform. The voltage waveform deviation factor[2] shall not exceed 10%. The frequency shall be maintained within ±0.5% of the value required for the test being conducted, unless otherwise specified. Tests shall be performed where the voltage unbalance does not exceed 1%. The percent voltage unbalance equals 100 times the maximum voltage deviation from the average voltage divided by the average voltage.

Direct current machines shall be supplied with the armature voltage and field current corresponding to the speed at which vibration is being measured. Vibration limits are based upon the use of low-ripple power supply A (see 12.66.2.1) type power sources. Other types of power supplies may be used for testing purposes at the discretion of the manufacturer.

7.7.3.3 Operating Speed

Unless otherwise specified, for machines having more than one fixed speed, the limits of this Part shall not be exceeded at any operational speed. For machines with a range of speeds, tests shall be performed at least at base and top speeds. Series DC motors shall be tested only at rated operating speed. For inverter-fed machines, it shall be acceptable to measure the vibration at only the speed corresponding to a 60 Hz power supply.



*Delete axial direction if not accessible

Figure 7-2
Preferred Points of Measurement Applicable
to One or Both Ends of the Machine

[2] The deviation factor of a wave is the ratio of the maximum difference between corresponding ordinates of the wave and of the equivalent sine wave to the maximum ordinate of the equivalent sine wave when the waves are superimposed in such a way as to make this maximum difference as small as possible. The equivalent sine wave is defined as having the same frequency and the same root mean square value as the wave being tested.

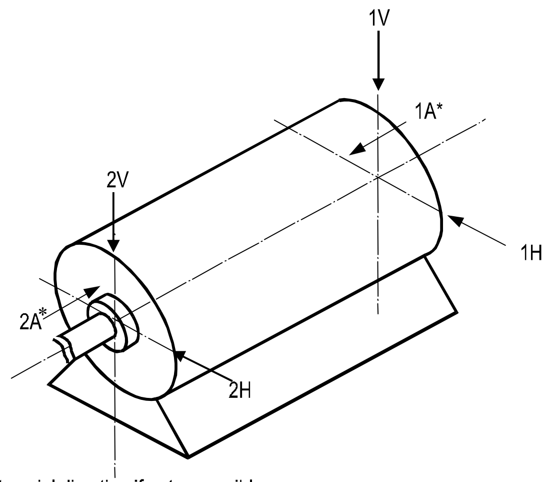


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Figure 7-3
Measurement Points for Those Ends of Machines Where Measurements Per Figure 7-2 Are Not Possible Without Disassembly of Parts

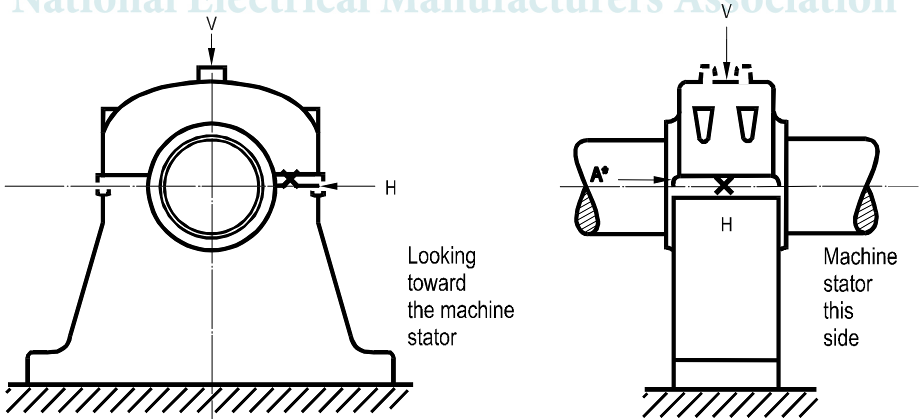

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Figure 7-4
Measurement Points for Pedestal Bearings

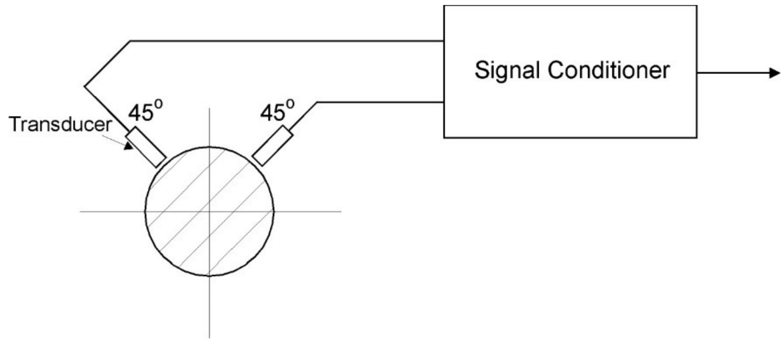

Figure 7-5
Preferred Circumferential Position of Transducers
for the Measurement of Relative Shaft Displacement

7.7.4 Vibration Transducer Mounting

Care should be taken to ensure that a contact between the vibration transducer and the machine surface is as specified by the manufacturer of the transducer and does not disturb the vibratory condition of the machine under test. The total coupled mass of the transducer assembly shall be less than 2% of the mass of the machine.

7.8 Limits of Bearing Housing Vibration

7.8.1 General

The following section defines the limits of vibration for machines running at no load, uncoupled, for vibration grades A and B. See Table 7-1.

Grade "A" applies to machines with no special vibration requirements. Grade "A" is supplied as standard unless the customer specifies grade "B."

Grade "B" applies to machines with critical vibration requirements and must be specified by the purchaser.

The preferred method of measurement is unfiltered velocity and the limits are as given in Table 7-1.

Vibration levels shown in the following paragraphs represent internally excited vibration only. Machines as installed (in situ) may exhibit higher levels. This is generally caused by misalignment or the influence of the driven or driving equipment, including coupling, or a mechanical resonance of the mass of the machine with the resilience of the machine or base on which it is mounted.

In Table 7-1, vibration limits are given in mils peak-to-peak displacement and in./s peak velocity. Vibration at frequencies above 1000 Hz should be filtered out.

Table 7-1
Unfiltered Housing Vibration Limits

NEMA Frame Size		NEMA Frame ≤ 210		NEMA Frame > 210	
Vibration Grade	**Mounting**	**Displacement, mils pk-pk**	**Velocity in./s pk**	**Displacement mils pk-pk**	**Velocity in./s pk**
A	Resilient	2.4	0.15	2.4	0.15
	Rigid	N/A	N/A	1.9	0.12 *0.15
B	Resilient	1.0	0.06	1.6	0.10
	Rigid	N/A	N/A	1.3	0.08 *0.10

* This level is the limit when the twice line frequency vibration level is dominant as defined in clause 7.8.5.

Note 1: Grade "A" applies to machines with no special vibration requirements.

Note 2: Grade "B" applies to machines with special vibration requirements. Rigid mounting is not considered acceptable for machines with shaft heights less than NEMA frame size 210.

Note 3: The manufacturer and the purchaser should take into account that the instrumentation can have a measurement tolerance of ±10%.
Note 4: A machine that is well-balanced in itself and of a grade conforming with Table 7-1 may exhibit large vibrations when installed on-site arising from various causes, such as unsuitable foundations, reaction of the driven machine, current ripple from the power supply, etc. Vibration may also be caused by driving elements with a natural oscillation frequency very close to the excitation due to the small residual unbalance of the rotating masses of the machine. In such cases, checks should be carried out not only on the machine but also on each element of the installation (See ISO 10816-3).

Note 5: As in ISO 20816-1, for on-site operations, special agreements can be made. The values given in ISO 20816-1 Table 1b are the basis for the ease of discussion and agreement between the supplier and the user. The values should ensure in most applications that major errors or unrealistic requirements are avoided. Special agreements shall also be made for acceleration and deceleration ramps. Short-term vibration limits and reduced bearing lifetime as a function of vibration velocity can be given by the manufacturer.

The vibration magnitude for DC and three-phase AC machines, for one of either of the two mounting conditions according to 7.6, shall not exceed the limits specified in Table 7-1. The shaft height of a machine without feet, or a machine with raised feet, or any vertical machine is to be taken as the shaft height of a machine in the same basic frame, but of the horizontal shaft foot-mounting type.

Limits are given for two vibration grades. When no grade is specified, machines complying with this standard shall be grade “A.”

For routine tests of standard machines with rotational speeds less than or equal to 600 rpm, vibration is to be expressed in units of displacement, and for rotational speeds between 600 and 15000 rpm, vibration is to be expressed in units of velocity.

Note 1: When a routine test is made with a free-suspension mounting condition, a type test should also include testing with rigid mounting. This note is valid for the whole speed range of this standard.

Note 2: International Standards specify vibration velocity as rms in mm/s. To obtain an approximate mm/s rms equivalent, multiply the peak vibration in in./s by 18.

7.8.2 Vibration Limits for Standard Machines

[Section deleted]

7.8.3 Vibration Limits for Special Machines

[Section deleted]

7.8.4 Vibration Banding for Special Machines

[Section deleted]

7.8.5 Twice Line Frequency Vibration of Two-Pole Induction Machines

Two-pole induction machines may have electromagnetic excited vibration at twice the frequency of the power system. The correct evaluation of these vibration components requires a rigid mounting of the machine that complies with the requirements given in 7.6.3.

When type tests demonstrate a dominant twice line frequency component for machines having a NEMA frame > 210, the vibration magnitude limit in Table 1 (for Grade A) is increased to 0.15 in./s from 0.12 in./s or (for Grade B) is increased to 0.10 in./s from 0.08 in./s. Greater values are subject to prior agreement. A twice line frequency component is considered dominant when type tests demonstrate it to be greater than 70% of 0.12 in./s (for Grade A) or 70% of 0.08 in./s (for Grade B).

Note 1: With respect to the twice line frequency component, agreements between the supplier and the customer can be made.

Note 2: 70% approximates $\frac{1}{\sqrt{2}}100\%$, where the rms values of rotational and twice line frequency are equal.

7.8.6 Axial Vibration

The level of axial bearing housing or support vibration depends on the bearing installation, bearing function, and bearing design, plus uniformity of the rotor and stator cores. Machines designed to carry external thrust may be tested without externally applied thrust. In the case of thrust bearing applications, axial vibrations correlate with thrust loading and axial stiffness. Axial vibration shall be evaluated per 7.7 and the limits of Table 7-1 apply.

Where bearings have no axial load capability or function, axial vibration of these configurations should be judged in the same manner as vibration levels in 7.8.1.

7.9 Limits of Relative Shaft Vibration

7.9.1 General

Shaft vibration limits are applicable only to sleeve bearing machines when probe mounting for non-contacting proximity probes is provided as part of the machine for machines rated >600 V and >1250 HP. Proximity probes are sensitive to mechanical and magnetic anomalies of the shaft. This is commonly referred to as "electrical and mechanical probe-track runout." The combined electrical and mechanical runout of the shaft shall not exceed the limits in Table 7-4. The probe-track runout is measured with the rotor at a slow-roll (100-400 rpm) speed, where the mechanical unbalance forces on the rotor are negligible. It is preferred that the shaft be rotating on the machine bearings, positioned at running axial center (magnetic center), when the runout determinations are made.

Note 1: Special shaft surface preparation (burnishing and degaussing) may be necessary to obtain the required peak-to-peak runout readings.

Note 2: Shop probes may be used for tests when the actual probes are not being supplied with the machine.

7.9.2 Shaft Vibration Limits

When specified, the limits for the relative shaft vibration of machines with sleeve bearings, inclusive of electrical and mechanical runout, shall not exceed the limits in Table 7-4.

Table 7-2

[Table deleted]

7.9.3 Special Machines

[Section deleted]

Table 7-3

[Table deleted]

Table 7-4
Shaft Vibration Limits

Maximum Relative Shaft Vibration (Including Electrical and Mechanical Probe Runout)			Maximum Combined Mechanical and Electrical Runout, mils
Vibration Grade	**Speed Range**	**Max Displacement, mils pk-pk**	
A	>1800	2.6	0.65
	≤ 1800	3.5	0.88
B	>1800	1.5	0.45
	≤ 1800	1.5	0.45

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