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GENERAL MOTORS / DELPHI VIBRATION STANDARD
FOR THE PURCHASE OF NEW and REBUILT
MACHINERY AND EQUIPMENT

GMNA

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GM-1761

TOC

We dedicate this revision to Mr. James H. Pyne, retired in 1997, through whose efforts the original V1.0-1994 would not have been practical or possible. Enjoy your retirement Jim!

GENERAL MOTORS CORPORATION

VIBRATION STANDARDS COMMITTEE

We would like to take this opportunity to extend a Thank You and word of appreciation to the members of the GM Vibration Standards Committee listed below and their sponsoring plants for their efforts and support during the development of this document.

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Note: Questions or comments pertaining to this standard should be sent to NA Manufacturing Reliability & Maintenance Operations at the address above. These questions and comments will be used in the periodic review of this standard.

TOC

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GENERAL MOTORS CORPORATION

VIBRATION STANDARD

FOR NEW AND REBUILT MACHINERY AND EQUIPMENT

FOREWORD

General Motors Corporation requires Vibration Certification of all new and rebuilt machinery and equipment in keeping with its implementation of Synchronous Processes and Lean Manufacturing. Vibration analysis and certification, as a part of machine performance evaluation will:

- Maximize part quality, machine productivity, tooling and machine life.
- Minimize machine installation and set-up time.
- Allow verification of machine performance and "health" throughout the machine's life.

The GENERAL MOTORS CORPORATION VIBRATION STANDARD FOR NEW AND REBUILT MACHINERY AND EQUIPMENT provides **COMMON** engineering performance guidelines for use by GM divisions and plants as well as machinery and equipment builders during the design, development, and build of new equipment and the rebuild of existing equipment. The vibration limits specified by the user and acknowledged by the machine manufacturer establish a common goal of acceptability by both parties. Such limits also enable machine manufacturers to provide evidence of the superiority and build integrity of their product.

The Vibration Limit values specified in this document are maximum vibration acceptance levels for **New** and **Rebuilt** machinery and equipment. These limits **ARE NOT** predictive maintenance warning or alarm level limits to be applied to equipment that has been in service for some period of time. If the machine builder is unable to provide information as to predictive maintenance warning and/or alarm levels for the specific equipment being considered, the following "Action Level Rules-of-Thumb" can generally be applied until specific fault vibration warning and alarm characteristics for said machine are developed through experience:

- Set "First Warning" vibration levels at 1.5X the applicable New and Rebuilt machine maximum acceptance levels for the machine under consideration. This First Warning Level would indicate a problem has developed and its' severity has reached a point where, although the machine can continue to be run, more frequent monitoring of the machine's "Health" is recommended.
- Set "First Alarm" vibration levels at 2X the applicable New and Rebuilt machine maximum acceptance levels for the machine under consideration. This First Alarm Level would indicate the severity of the problem has reached a stage where the developing cause of the vibration needs to be identified, necessary repair parts identified and ordered (if not in crib stock), date for repair established based on minimum production interruption, and skilled trades personnel identified and scheduled for the repair. Although the machine can continue to be run, it should be closely monitored, particularly if it is a "critical machine".
- Set a "Second Alarm" vibration levels at 2.5X - failure pending or 3X - failure eminent. If the machine is a critical machine, it should be scheduled for PM repairs ASAP.

The above "Rules-of-Thumb" are generally conservative. In time, after experience with said machine, the vibration levels for Warning and Alarm can be adjusted to fit the specific machine health conditions.

TOC

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GENERAL MOTORS CORPORATION

VIBRATION STANDARD

FOR NEW AND REBUILT MACHINERY AND EQUIPMENT

TABLE OF CONTENTS

APPENDIX

TABLES

FIGURES

FIGURES

GENERAL MOTORS CORPORATION

VIBRATION STANDARD

FOR NEW AND REBUILT MACHINERY AND EQUIPMENT

1.0 PURPOSE

The purpose of this standard is to:

- Improve the life and performance of rotating machines and equipment purchased by General Motors Corporation.
- Reduce operating costs in General Motors plants by establishing acceptable vibration levels for new and rebuilt rotating machinery and equipment.
- Provide a uniform procedure for evaluating the vibration characteristics of a machine for certification and acceptance.

2.0 SCOPE

This standard establishes:

- Acceptable limits for vibration levels generated by new and rebuilt rotating machinery and equipment purchased by General Motors Corporation.
- Measurement procedures -- including standardized measurement axis directions and locations, calibration and performance requirements of instrumentation, and procedures for reporting vibration data for machine certification and acceptance.

3.0 INSTRUMENTATION REQUIREMENTS

Vibration measurements will be made with an FFT analyzer. The type, model, serial number(s) and latest certified calibration date of all equipment used in the measurement of vibration levels for machine certification, shall be recorded and made available upon request.

3.1 Hardware & Software

3.1.1 Hardware - FFT Analyzer

- The FFT Analyzer shall be capable of a line resolution bandwidth $\Delta f = 300$ CPM for the frequency range specified for machine certification unless this restriction would result in less than 400 lines of resolution, in which case the requirement defaults to 400 lines of resolution. (Higher resolution may be required to resolve "Side Bands," or in Band 1 to resolve machine vibration between 0.3X and 0.8X Running Speed.)
- The Dynamic Range shall be a minimum of 72 dB.
- The FFT analyzer shall be capable of applying a Hanning window.
- The FFT analyzer shall be capable of linear non-overlap averaging.
- The FFT analyzer shall have anti-aliasing filters.

TOC

3.1.2 Software:

The computer software used to program/analyze/store machine certification vibration data shall store the data in the Machinery Information Management Open Systems Alliance (MIMOSA) standard database structure, or provide full connectivity between systems through MIMOSA compliant import/export capability.

3.2 MEASUREMENT SYSTEM ACCURACY

3.2.1 The measurement system (FFT analyzer, cables, transducer and mounting) used to take vibration measurements for machine certification and acceptance **SHALL BE CALIBRATED** and have a ±5% measurement system Amplitude accuracy over the selected frequency range.

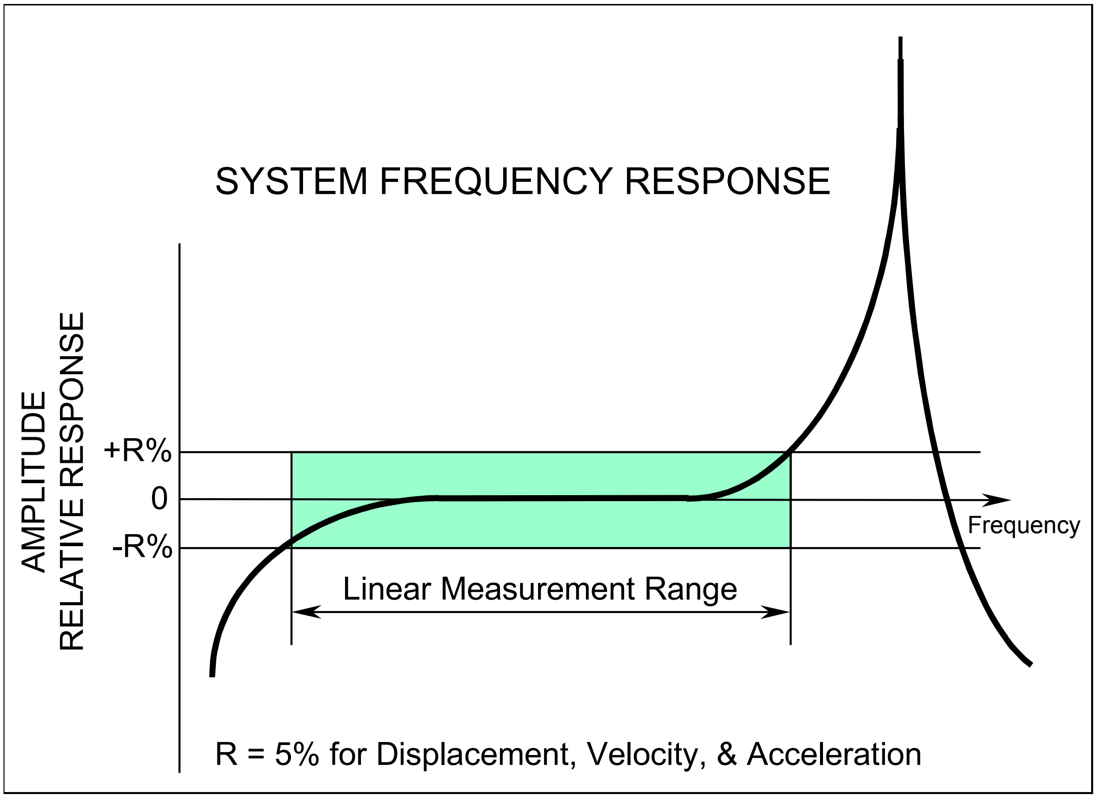


Figure 1 Measurement System Frequency Response

3.2.2 SYSTEM SIGNAL-TO-NOISE RATIO

The inherent measurement system noise must not exceed 10% of the amplitude limit at the lowest frequency of measurement. (I.e. the total measurement system signal-to-noise ratio must be ≥ 10:1)

3.3 MEASUREMENT SYSTEM CALIBRATION

Vibration equipment (transducer, preamplifier, FFT analyzer, recorder and connecting cable) used to take vibration measurements for machine certification and acceptance must be calibrated by a qualified instrumentation laboratory in accordance with Sections 5.1 and 5.2 of ANSI S2.17-1980 "Technique of Machinery Vibration Measurement" within one (1) year prior to the date of machine certification.

Calibration shall be traceable to the National Institute of Standards and Technology (NIST) in accordance with MIL-STD-45662 "Military Standard Calibration Systems Requirements" (10 June 1980) or latest revision.

TOC

3.4 VIBRATION SENSOR REQUIREMENTS

The following vibration sensor requirements **SHALL** be considered as minimum acceptable requirements for machinery and equipment acceptance certification. Sensors exceeding these requirements will also be considered for purchase and use.

3.4.1 An accelerometer shall be used in the collection of data for machine certification and acceptance. The accelerometer must be selected and attached to the machine in such a way that the minimum frequency (F_{MIN}) and maximum frequency (F_{MAX}) as specified in Section 9 or specified otherwise by the purchaser, are within the usable frequency range of the transducer and can be accurately measured (reference recommendations of pickup manufacturer and/or Section 6.3, ANSI S2.17-1980).

3.4.2 The mass of the accelerometer and its mounting shall have minimal influence on the frequency response of the system over the selected measurement range. (Typical mass of accelerometer and mounting should not exceed 10 % of the dynamic mass of the structure upon which the accelerometer is mounted.) Reference Appendix for Dynamic Mass definition and Procedure to Determine Mass Effect.

3.4.3 Integration is acceptable for converting acceleration measurements to velocity or displacement.

3.4.4 Accelerometers used for machinery and equipment acceptance certification shall meet the requirements specified in Table 1 (Vibration Sensor Requirements). Each model of accelerometer purchased by General Motors Corporation, shall be "Class" Certified Calibrated in compliance with ISO 10012-1, and former MIL-STD-45662A and traceable to NIST. A copy of the documented Calibration Certificate per ISA-RP37.2 shall be made available to the GM Vibration Standards Committee. The GM Vibration Standards Committee reserves the right to verify the hardware and the acceptability of the documentation. Also, a copy of the Calibration Certificate shall be available to GM purchasers upon request.

3.4.5 All Accelerometers shall be (Unless specified otherwise by the purchaser):
- Hermetically Sealed (Reference Table 1).
- Stainless Steel 316 or ≥ equivalent per application requirements.

3.4.6 Low and Midrange Frequency (Class 1A through Class 3A) Industrial Accelerometers shall meet the following:
- Military Connector two (2) pin per Mil Std. 5015 or equivalent performance as applicable to the specific accelerometer.
- Top mount, side mount, or integral cable connection to be determined by user, dependent on application.

3.4.7 Broadband and High Frequency (Class 4A through 5A) Accelerometers shall meet the following:
- For 50 mV/g and 100 mV/g Sensitivity, must be Military Connector two (2) pin per Mil Std. 5015 or equivalent performance as applicable to the specific accelerometer.
- For 10 mV/g Sensitivity, may use a Laboratory grade Connector (Microdot).

NOTE: Accelerometers **SHALL** be constructed such that they direct link to a portable data collector, and are compatible with plant equipment.

3.4.8 Other types of Vibration Sensors (such as a Laser Vibrometer) that meet or exceed the required performances specified above and in Table 1 are acceptable for use in meeting the requirements of this specification.

TOC

TABLE 1 VIBRATION SENSOR REQUIREMENTS

Transducer Class and Frequency Type	Class 1A UltraLow Frequency	Class 2A Low Frequency	Class 3A Mid-range Frequency	Class 4A Broad-range Frequency	Class 5A High Frequency
Frequency Range Stud Mounted, (± 5%)	0.2 - 200 Hz	0.5 - 2,000Hz	10 - 5,000 Hz	10 - 9,000 Hz	10 - 25,000 Hz with ± 10% Sens. Tolerance
Frequency Range Direct Mounted-Adhesive (± 5%)	0.2 - 200 Hz	0.5 - 2,000 Hz	10 - 5,000 Hz	10 - 9,000 Hz	
Frequency Range Magnet Mounted, (± 5%)		0.5 - 1,700 Hz	10 - 2000 Hz	10 - 3,000 Hz	
Sensitivity (± 5%)	10,000 mV/g	500 mV/g	*50 mV/g	*50 mV/g or 10 mV/g	10 mV/g
Turn-on time (sec) [Settling time within 1% of output bias]		5.0	3	3	3
Resolution (g)	0.000001	0.00001	0.0002	0.0002	0.005
Transverse Sensitivity	<3%	<5%	<5%	<5%	<5%
Strain Sensitivity g/micro-strain	NA	0.0006	0.0008	0.0006	0.015
Package	Industrial	Industrial	Industrial	Industrial or Laboratory (i.e. Microdot)	May be Laboratory i.e. Microdot
Shock Protect		5000g	5000g	5000g	5000g
Output Voltage	Shall be in direct proportion to Acceleration				
Electromagnetic Sensitivity	Conform to EMC CE Requirements				
Seal	Hermetic $< 2 \times 10^{-8}$ cc/s of Helium @ 1 ATM.				
Etching	GM class number with Actual-Measured Sensitivity @ 100 Hz.				

- 50 mV/g Preferred, 100 mV/g Allowed Vendor shall submit ISO/QS 900X test data procedures upon request (ref. 3.4.4, p. 3).

4.0 CONVENTION FOR IDENTIFYING VIBRATION MEASUREMENTS

4.1 Vibration measurement locations documented for certification and acceptance on the machine layout drawing and on any vibration data submitted SHALL follow the following conventions. These conventions define the system, machine, station, component part, location, sensor type and orientation separately.

- **System** (e.g. Crank Line #1, Leak Test, Final Assembly, etc.) -- Alphanumeric description limited by record documentation media. (E.g. machine layout drawing, software, etc.) Description to be agreed upon by purchaser and supplier.
- **Machine** (e.g. Operation 10, Grinder, Mig welder, Hydraulic Unit, etc.) -- Alphanumeric description limited by record documentation media. (E.g. machine layout drawing, software, etc.)
- **Station** (e.g. 445, Rough Bore, Underbody Weld, etc.) -- Alphanumeric description limited by record documentation media.
- **Optional Description** (e.g. Low speed measurement, Measurement under load, Stud Mounted Transducer, etc.) -- Alphanumeric description limited by record documentation media.

> NOTE: **System, Machine, Station,** and **Optional Description** documentation may not always be applicable. For example, if the *machine* being purchased - new or rebuilt - is a motor.

- **Component Part** (e.g. motor, shaft, auxiliary gearbox, etc.): Four (4) alphanumeric characters
- **Location** (e.g. bearing number designation): Three (3) numeric characters
- **Sensor** (transducer) Type Code: Two (2) letters
- **Angular Orientation**: Three (3) digits (000 to 360 degrees)
- **Sensor Axis Orientation**: One (1) letter
- **Direction of Motion**: One (1) letter

TOC

The six convention definitions (Component Part, Location, Sensor, Angular Orientation, Sensor Axis Orientation and Direction of Motion) SHALL be combined into fourteen character (no spaces) measurement identification as follows:

E.g. SFTA003AC090RN (shaft A, bearing number 3, single axis accelerometer positioned 90 degrees counterclockwise from zero, mounted radially, normal motion).

This convention for specifying transducer type and angular orientation at each measurement location **IS REQUIRED** for General Motors / MIMOSA compliance.

4.1.1 Component Part (shaft, gearbox, roll, etc.): four (4) alphanumeric characters

Four user defined alphanumeric characters provide a flexible means to identify specific component parts of a machine for convenience and purposes of automated diagnosis. Examples include individual shafts rotating at different speeds within a complete machine i.e. SFTC to indicate shaft C, an auxiliary gearbox with multiple shaft speeds that differ from the shaft speeds of the main machine i.e., AGB6 (auxiliary gearbox, position number 6).

Reference Appendix A “RECOMMENDED COMPONENT IDENTIFICATION SYMBOLS”. Since component identification utilizes only three (3) primary alpha characters, (e.g. SFT for shaft), the fourth character space will be a “null” identified by the symbol (@), alpha character such as (A), or a numerical character such as (6).

4.1.2 Location (bearing number designation): three (3) numeric characters

A numeric sequence identifying the specific bearing on which a vibration measurement is recorded using three numeric numbers. For purposes of this Specification, the numeric sequence starts at the outboard bearing position of the driver machine (MOTOR), which is designated, as location 001. Reference Figures 2, 4, 5A, 6A, 6B, and 6C.

4.1.3 Sensor (transducer) Type Code: two (2) letters

Sensor type is designated by a two-letter abbreviation according to the following table:

AA	Single Axis Accelerometer	PD	Dynamic Pressure
AC	Single Axis Accelerometer w/internal integration	PS	Static Pressure
AT	Triaxial Accelerometer	SG	Strain Gage
CT	Current Transformer	TC	Temperature--Thermocouple
DP	Displacement Probe	TR	Temperature -- RTD
DR	Displacement Probe used as a Phase Reference	TT	Torque Transducer
LT	LVDT (Linear Voltage Differential Transformer)	TO	Torsional transducer
MP	Magnetic Pickup (shaft speed/phase reference)	VP	Velocity Pickup
MI	Microphone	VT	Voltage
OP	Optical Pickup (shaft speed/phase reference)	OT	Other

4.1.4 Angular Orientation: three digits (000 to 360 degrees)

4.1.4.1 Foot-Mounted Machines: The angular position of a vibration sensor is measured from a zero reference located at 3 o’clock when viewed at position number 001, looking into the machine. The 12:00 o’clock position on the machine surface is opposite the machine mounting plate--Reference Figure 2.

The angle increases counterclockwise (regardless of the direction of shaft rotation) in the plane of shaft rotation from 0^o to 360^o.

4.1.4.2 Flange Mounted Machines: The angular position of a vibration sensor is measured from a zero reference located at the *Point of Energy Input* on the Driver Machine. When viewed from Position 001 looking into the machine (in the direction from Driver to Driven). The angular position increases counterclockwise (regardless of the direction of shaft rotation) in the plane of shaft rotation from 0^o to 360^o.

TOC

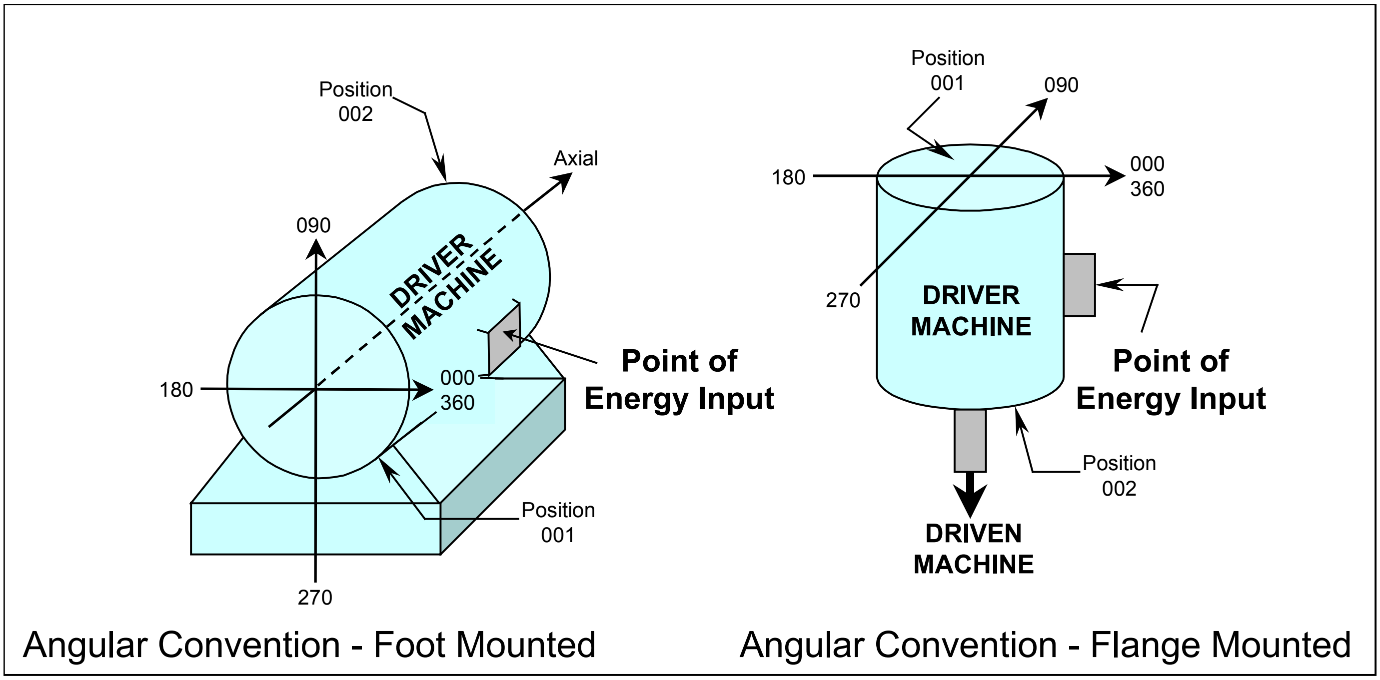


Figure 2 Angular Convention for Foot Mounted & Flange Mounted Machines

4.1.5 Sensor (sensitive) Axis Direction (Orientation): one (1) letter

A single letter defines the direction of the sensor sensitive axis. This portion of the identification provides unique descriptive information when the sensor sensitive axis does not coincide with the radial defined in the previous section (Reference Figure 3: XXXAC135H, XXXAC090T, and XXXAC315A). It is redundant when the sensitive axis coincides with the defined radial (e.g. XXXAC000R and XXXAC000H).

R - Radial: sensor sensitive axis perpendicular to and passes through the shaft axis
A - Axial: sensor sensitive axis parallel to the shaft axis

NOTE: Axial direction (A) shall be, by definition, parallel to the rotational axis of the machine.

T - Tangential: sensor sensitive axis perpendicular to a radial in the plane of shaft rotation
H - Horizontal: sensor sensitive axis orientated at 000 or 180 degrees only
V - Vertical: sensor sensitive axis orientated at 090 or 270 degrees only

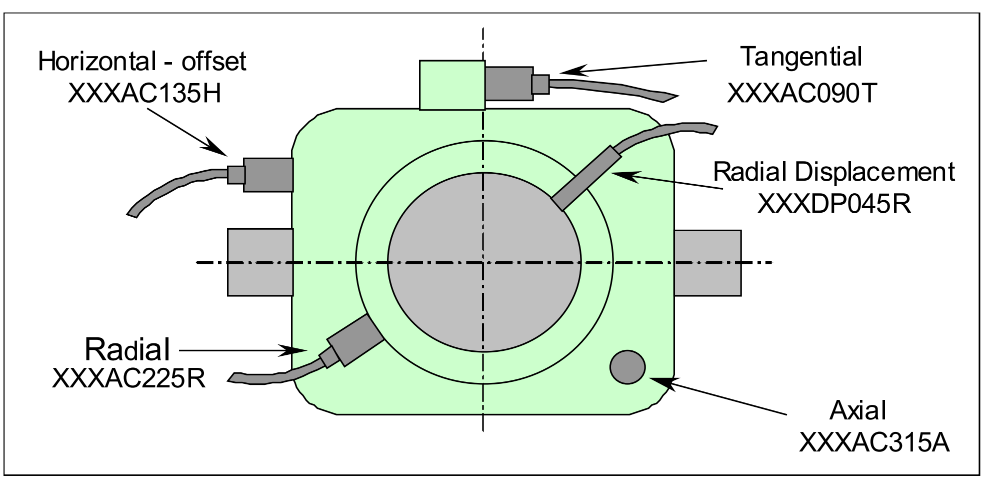


Figure 3 Direction of Sensor Axis

TOC

4.1.6 Motion for a positive signal output (relative to a Time Waveform):

4.1.6.1 Motion into the sensor is defined as positive (+), motion away from the sensor is negative (-).

4.1.6.2 When radial sensors are installed in an X-Y pair, the X sensor will be 45 degrees to the right (clockwise) from a radial bisecting the angle between the two sensors when viewed from position number 001 (regardless of the direction of shaft rotation). The Y sensor will be 45 degrees to the left (counterclockwise) from the bisecting radial.

4.1.7 Direction of Motion: [one (1)letter]

The final character in the measurement identification code is either an N (normal) or R (reverse) to identify sensors mounted in opposition where machine motion in one direction results in positive motion in one sensor (N -- normal) and negative motion (R -- reverse) in the other. Axial sensors mounted in opposite directions at opposing ends of a machine are the primary example. Axial machine motion toward the reference end is normally designated positive. The axial sensor closest to the reference end of the machine, position 001, will be designated normal (N) when mounted such that positive motion toward the sensor produces a positive signal output. Likewise, motion toward the reference end will produce a negative signal from the axial sensor at the opposite end, which is then designated R (reverse). The angular orientation defines the direction of motion for radially mounted sensors. Therefore, default of N (normal) should be utilized for sensors mounted radially.

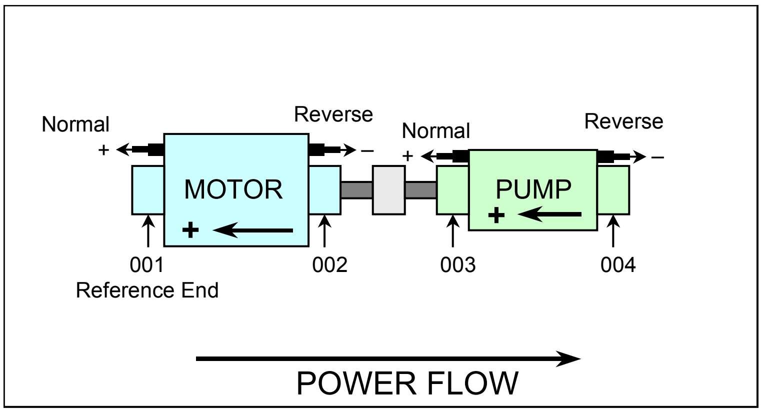


Figure 4 Normal and Reverse Motion Convention

5.0 VIBRATION MEASUREMENT LOCATIONS

Required measurement positions and orientations on a machine's surface at which vibration measurements are to be taken shall be determined by mutual agreement of the purchaser and the machine builder, and shall meet the following requirements:

5.1 Follow the convention specified in Sections 4.0 and 5.0, unless specified otherwise by the purchaser.

5.2 If an obstruction or a safety concern prevents locating a transducer as specified, locate as close as possible to the standardized position.

5.3 Measurement locations used for machine certification and acceptance shall be identified on the machine layout drawing and/or machine as mutually agreed upon by the purchaser and the machine builder.

5.4 Vibration measurement locations shall be on a rigid member of the machine, as close to each bearing as feasible. Bearing housings, machine casings or mounting blocks are examples of mounting locations.

5.5 Vibration measurement location shall NOT be on a flexible cover or shield such as the fan covering on an electric motor or a sheet-metal belt guard.

TOC

5.6 Guarding must be designed to allow accessibility to all measurement locations (Reference Section 5.7).

5.7 In the event that vibration monitoring points will be rendered inaccessible after the machine is built or access to the measurement points would present a safety problem during measurement, permanently mounted transducers (Stud Mounted or Adhesive Mounted) **SHALL BE** installed. Installation shall be in accordance with the requirements set forth in Section 6 of this document.

5.8 Measurement locations shall be numbered consecutively from 001 to NNN in the direction of power flow:

5.8.1 Position 001 designates the *out-board starting* Power Point bearing location of the driver unit of the machine. Position NNN designates the bearing location at the *terminating* Power Point bearing location of the driven machine (Reference Figures 4, 5A, 6A, 6B, and 6C).

5.8.3 When a machine station consists of multiple components, such as two or more spindles, consecutive numbering of components shall be in the direction of process flow (Reference Figures 5A and 5B).

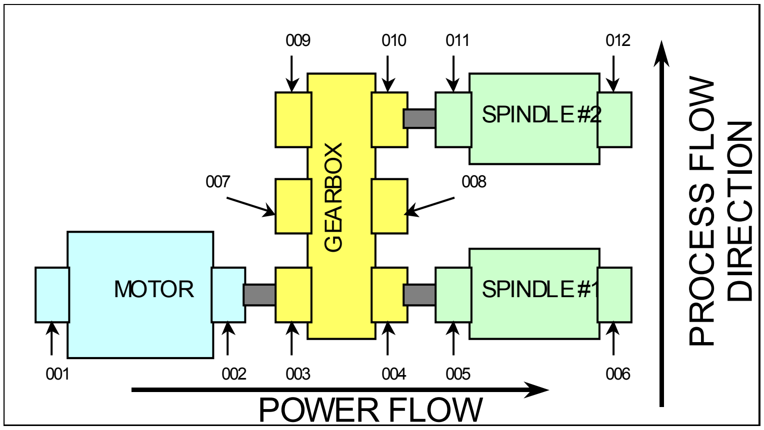


Figure 5A Order and Consecutive Numbering Sequence

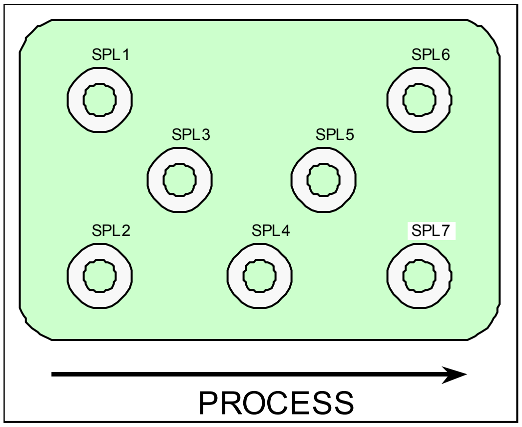


Figure 5B Order and Consecutive Numbering Sequence

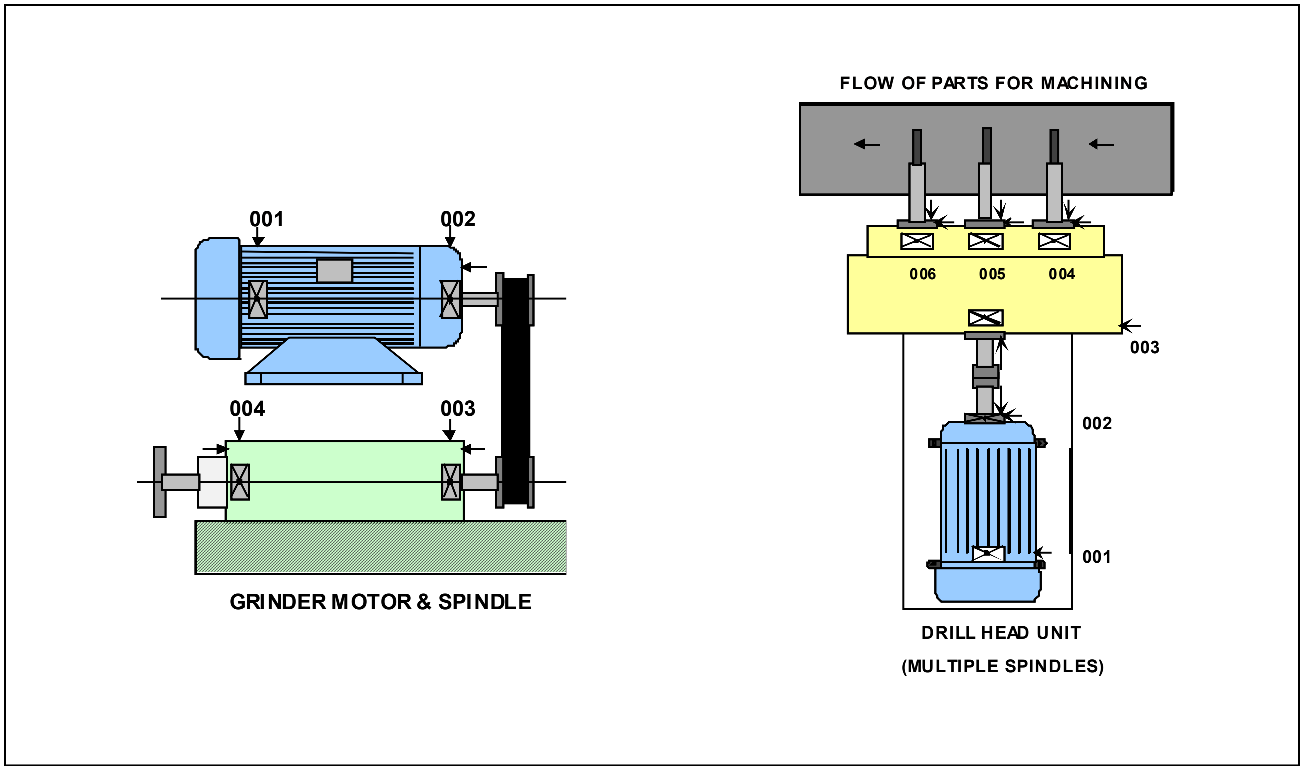


Figure 6A Vibration Measurement Locations

TOC

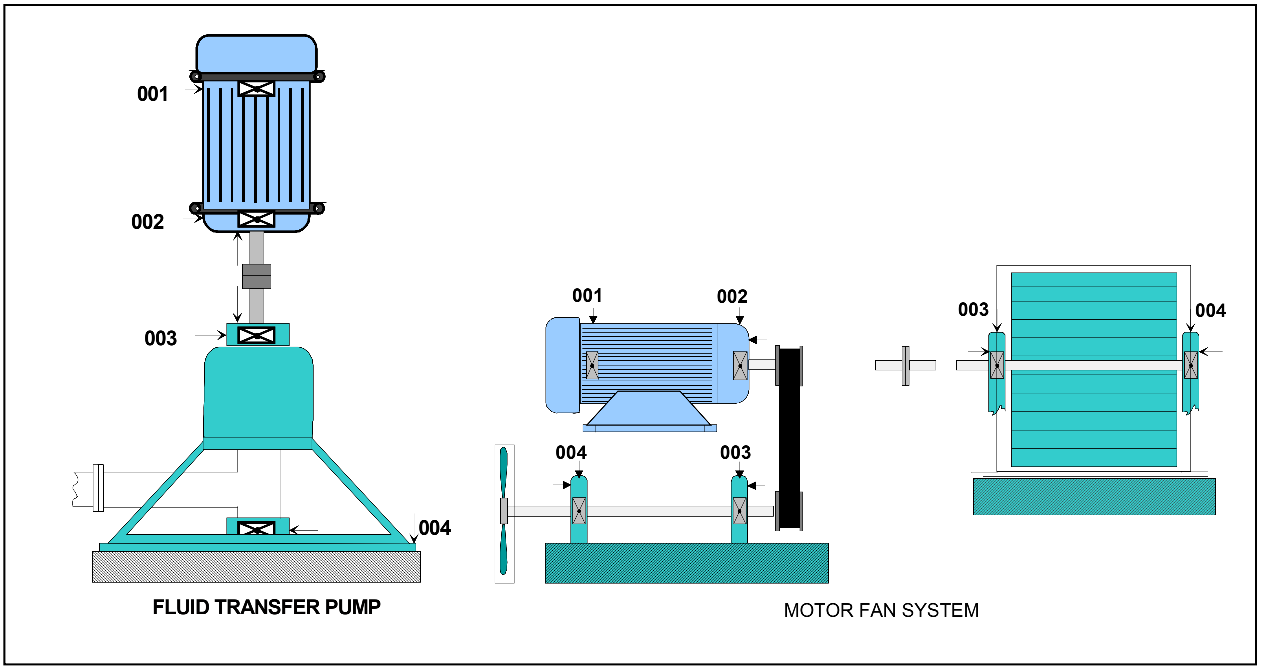


Figure 6B Vibration Measurement Locations

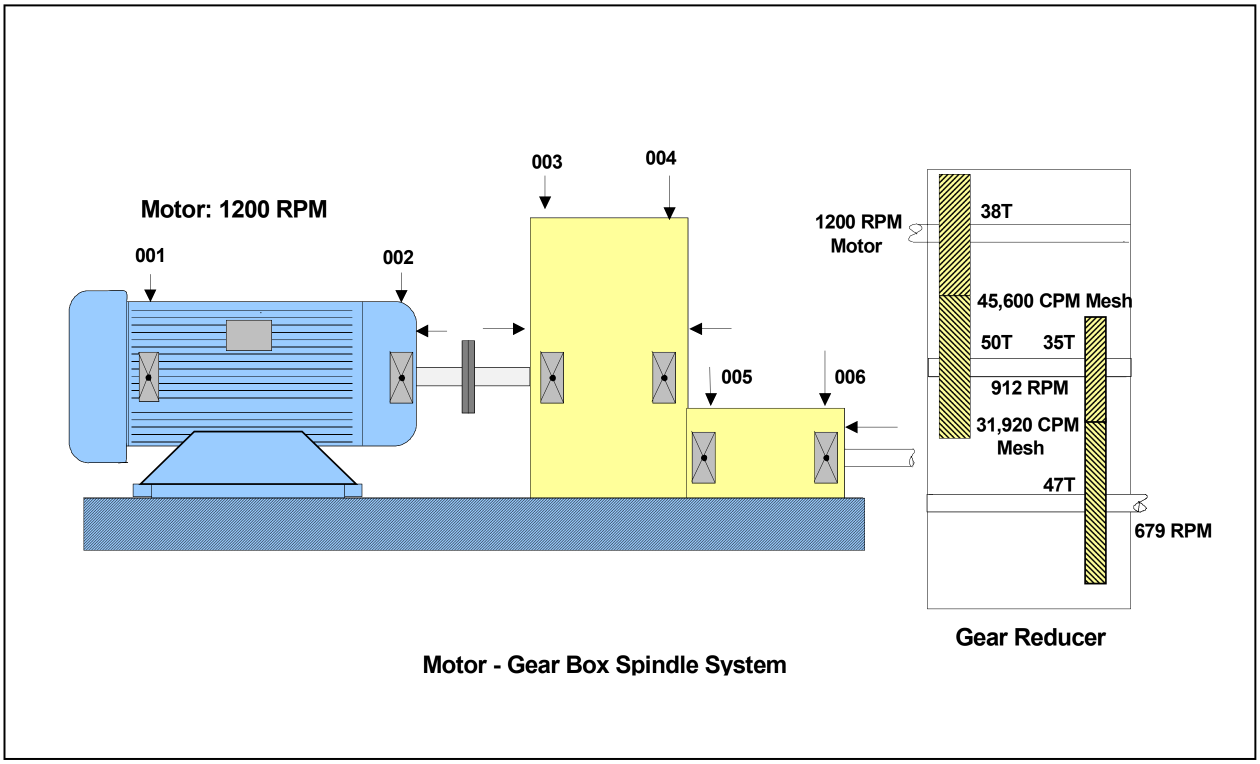


Figure 6C Vibration Measurement Locations

TOC

6.0 TRANSDUCER & MACHINE MOUNTING CONDITIONS

6.1 VIBRATION TRANSDUCER MOUNTING

The mounted vibration transducer must provide the measurement system amplitude accuracy over the selected frequency range equal to or exceeding the requirements specified in Section 3.2.

At the designated measurement positions, suitable surfaces shall be provided such that the mounted transducer will attach securely.

6.1.1 **Hand-held Pickups**: Hand-held pickups are not acceptable for certification measurements by this specification. They may be used for surveying machine surfaces for identification of suitable pickup locations.

6.1.2 **Magnetic Mount**: For a magnetic base mounted transducer the location on a machine's surface at which vibration measurements are to be taken shall be machined (faced) or cast 1.1 X Diameter of the mounting surface of the magnet to be set on the Surface, flat within 25 µm (1 mil), and a minimum surface finish (surface texture) of 25 µm (1 mil). During measurement, the mounting location shall be clean, free of debris and paint, so that the magnet base can be attached firmly without *rocking*.

> NOTE: Purchaser will specify to the machine tool builder the largest magnet diameter for which machined or cast surfaces will need to be provided.

6.1.3 **Stud Mounted**: For a stud mounted transducer, the machine's surface at which vibration measurements are to be taken shall be machined (faced) with a minimum surface diameter of 1.1 X Diameter of the mounting surface of the transducer to be mounted on the Surface, flat within 25 µm (1 mil), and a minimum surface finish (surface texture) of 25 µm (1 mil).

> NOTE: Purchaser will specify to the machine tool builder the largest transducer diameter for which machined surfaces will need to be provided.

The tapped hole shall be M6 x 1H (¼ x 28), unless otherwise specified, with a minimum depth of at least two threads deeper than the stud. The hole shall be perpendicular to within 1^{o} to the mounting surface.

Refer to Accelerometer manufacturer's literature for mounting parameter requirements (torque, grease, etc.).

Designated transducer type to be specified by the purchaser.

6.1.4 **Adhesive Mounting**: Adhesives will lower the accelerometer mounted resonance frequency (usually specified for stud mounted). If an adhesive is used to attach either the transducer or a magnetic mounting pad, the upper frequency limit of the transducer shall be reduced by 20% of the manufacturer's stated resonance for *hard* adhesives and by 50% of the manufacturer's stated resonance for *soft* adhesives. Transducer manufacturer's specifications should be consulted.

The machine's surface at which vibration measurements are to be taken shall be machined (faced) with a minimum surface diameter of 1.1 X Diameter of the mounting surface of the transducer to be mounted on the Surface, flat within 25 µm (1 mil). The surface shall be abraded to approximately 25 µm (1 mil) to increase adhesion. The adhesive bond layer thickness should be less than 1 mm.

6.2 MACHINE MOUNTING

6.2.1 Where a machine can be tested as an individual unit (e.g. motor, spindle, etc.) the machine must be mounted as specified in Section 9.

6.2.2 Where an individual machine can be tested only as an assembled unit (e.g. motor/pump, motor/fan, etc.), the machine mounting conditions shall be as equivalent as possible to those to be encountered upon installation at the purchaser's site.

TOC

7.0 TECHNICAL REQUIREMENTS

7.1 VIBRATION MEASUREMENT UNITS

Vibration measurements and data for machine certification and acceptance shall be in the RMS-METRIC units specified in Table 2.

NOTE: During transition from English to Metric, equivalent English values in units specified in Table 2 may also be included in the data if enclosed by ( ).

TABLE 2 - Vibration Measurement Units

Frequency	Orders, Hertz, (CPM)	
Rotational Speed	Revolutions per Sec [RPS] or Revolutions per Minute [RPM]	
Amplitude	METRIC	ENGLISH
• Displacement (Peak or Peak-to-Peak)	Micrometers	Inch (Also Mil in U.S.)**
• Velocity	Millimeter/sec (RMS)	Inch/sec (Peak)
• Acceleration	Meter/sec^2 or g's (RMS)	g's (Peak)

** 1 "Mil" = .001 inch

If "True Peak" measurements are required, time domain data will need to be acquired. The units of measurement will be Metric and designated by the words "True Peak".

NOTE: What is normally referred to as "Peak" or "Peak-to-Peak" Vibration Amplitude Measurements is a Calculated Peak not a True Peak. The Calculated Peak is derived from the RMS level based on the following equations:

Peak (P) = 1.414 x RMS   Peak-to-Peak (P-to-P) = 2 x (P) = 2 x 1.414 x RMS

7.2 FREQUENCY BANDS

The frequency range of measurement shall be divided into sub-groups called bands. The F_{min} and F_{max} for each band will be defined in units of frequency or orders of running speed of the machine (Ref. Figure 7).

7.2.1 **Mandatory Bands**
Band 1 shall be (0.3 - 0.8) X Running Speed [1st Order]
Band 2 shall be (0.8 - 1.2) X Running Speed [1st Order]
Band 3 shall be (1.2 - 3.5) X Running Speed [1st Order]

7.2.2 **Other Bands**
Bands 4 through N shall be defined by the specific machine tool application. Bands 4 through N may also overlap each other or be contained within each other (such as a "Zoom" Band) as required by a specific application.

TOC

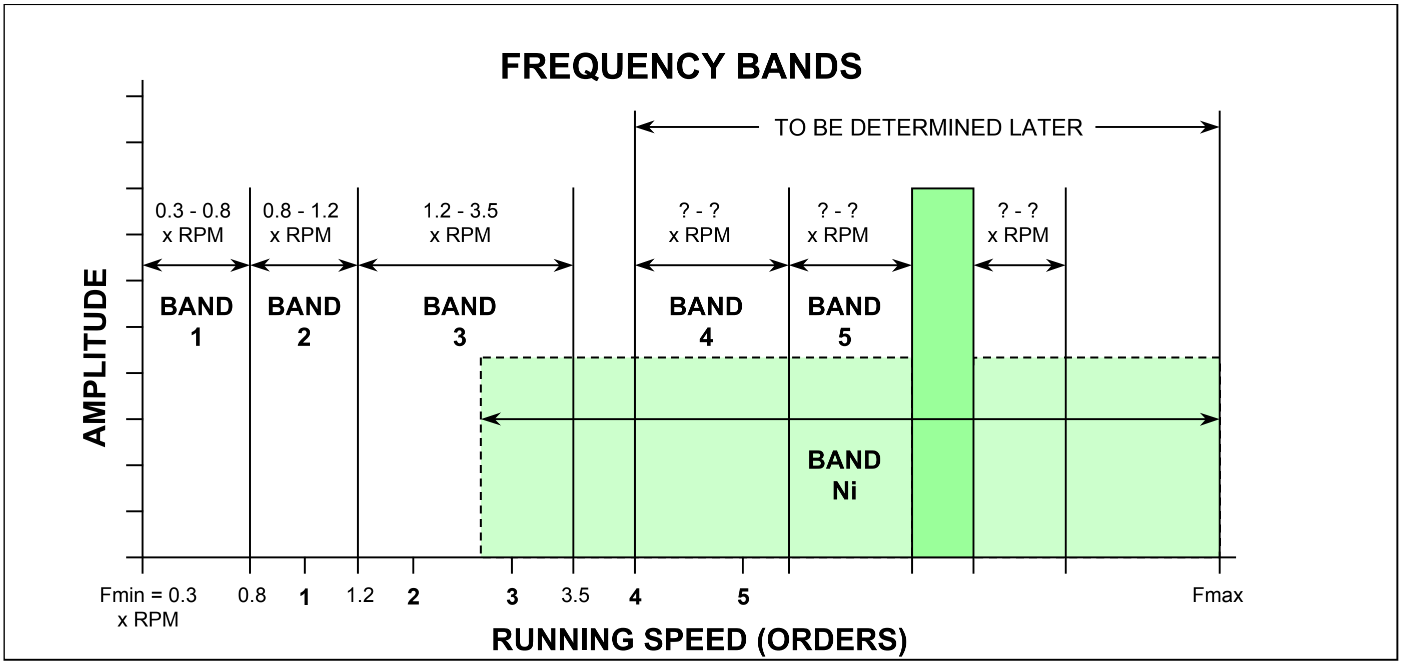


Figure 7 Frequency Bands

7.2.3 **Maximum Frequency F_{max}**

Vibration spectra plots consisting of Amplitude vs. Frequency shall span a frequency range with upper frequency limit F_{max}, and have sufficient resolution so as to include and resolve minimum and maximum frequencies of interest, such as due to drive belts, mechanical looseness, imbalance, misalignment, bearing defects, gear mesh, applicable side bands, etc. As a general guideline for frequency range, F_{max} = 3.25 times gear mesh or 50 times running speed, whichever is greater. Additional frequency range plots spanning a more limited range, or "Zoom," is acceptable to meet resolution requirements.

7.3 LINE AMPLITUDE ACCEPTANCE LIMITS

For vibration level limits specified in terms of "LINE AMPLITUDE ACCEPTANCE LIMITS":

- A line of resolution will have a band width (Δf) = 5 Hertz (300 CPM) unless specified otherwise (Reference Section 7.4 requirement for total energy in a peak), unless the Δf = 5 Hertz (300 CPM) restriction would result in less than 400 lines of resolution over the frequency range specified for certification, in which case the resolution requirement will default to 400 lines. Greater resolution, i.e. Δf < 5 Hz (300 CPM) may be required for low speed equipment, to resolve "Side Bands," or in Band 1 to resolve machine vibration between 0.3X and 0.8X Running Speed.

- The maximum amplitude of any line of resolution contained within a band shall not exceed the Line Amplitude Acceptance Limit for the Band.

> NOTE: If a line of resolution is coincidental with the F_{min}/F_{max} of two adjacent bands, that line of resolution will be included in "Line Amplitude Acceptance Limit" evaluation for each band.

TOC

7.4 BAND-LIMITED OVERALL AMPLITUDE ACCEPTANCE LIMITS

For vibration level limits specified in terms of "BAND-LIMITED OVERALL AMPLITUDE ACCEPTANCE LIMITS" the Total vibration level "A" in a band, as defined by the following equation, shall not exceed the Overall Amplitude Acceptance Limit specified for the Band.

$$A = \sqrt{\frac{\sum_{i=1}^{N} A_i^2}{1.5}}$$

A	=	Overall vibration level in the Band
A_i	=	Amplitude in the i^{th} line of resolution in the Band
(i = 1)	=	The first line of resolution in the Band
(i = N)	=	The last line of resolution in the Band
N	=	The number of lines of resolution in the Band

If the total energy in a peak is to be measured, a minimum of 5 lines of resolution must be used and the peak must be centered in the band.

> NOTE: If a line of resolution is coincidental with the F_{min}/F_{max} of two adjacent bands, that line of resolution will be included in the "Band-Limited Overall Amplitude Acceptance Limit" evaluation for the band having the lowest acceptance level limit.

7.5 The amplitude range sensitivity of the FFT Analyzer shall be set to the maximum input sensitivity possible without overloading such that the actual measurement uses at least 72 dB of the Dynamic Range.

7.6 Certification will be based on:

- Hanning Window.
- Four (4) averages (Linear non-overlapping).

7.7 The transducer mounting shall be such that the measurement system amplitude accuracy over the selected frequency range equals or exceeds the requirements specified in Section 3.2. This may require the use of more than one accelerometer where potentially high frequencies might occur (such as gear mesh or harmonics of gear mesh) along with lower frequencies (such as due to imbalance, misalignment, looseness, etc.).

7.8 ALIGNMENT

All coupled rotating machines consisting of consecutive shafts connected through a coupling (whether rigid or flexible) shall be aligned within the tolerances specified by the purchaser in the "Request for Quote." If the Purchaser does not specify an alignment tolerance, the requirements of this Standard defaults to the tolerance limits specified in GM Specification No. A1.0-1997, "GENERAL MOTORS CORPORATION LASER ALIGNMENT SPECIFICATION FOR NEW AND REBUILT MACHINERY AND EQUIPMENT," (Or Latest Revision).

Consideration shall be given to any thermal growth that might occur during the normal operation of the machine that would cause the machine to "grow out of alignment" to the extent that the alignment tolerances of this specification would not be met.

7.9 BALANCING - Shaft and Fitment Key Convention

7.9.1 STANDARD KEY

7.9.1.1 For rotating machines and machine components with a keyed shaft, this Standard requires balancing be achieved using a standard one-half key in the key seat in accordance with ISO 8821-1989(E). ISO 8821-1989(E) applies to rotors balanced in balancing machines, in their own housings, or *in situ,* and applies to keys of constant

TOC

rectangular or square cross-section, keys mounted on tapered shaft surfaces, woodruff, gib, dowel and other special keys.

7.9.1.2 If a full key, corresponding to the half key used for balancing, is not provided with the rotating machine, a tag, as shown in Figure 8, will be attached to the machine indicating the dimensions of the key used to perform the balance test.

7.9.1.3 If no key is shipped with the shaft, and a tag as shown in Figure 8 is not attached to the shaft, the length of the half-key used originally for balancing the shaft is assumed to be the same as the length of the shaft keyway (Ref. ISO 8821).

7.9.2 The use of solder or similar deposits to achieve rotor balance is not acceptable. Any parent metal removed to achieve dynamic or static balance shall be drilled out in a manner, which will maintain the structural integrity of the rotor.

A = "Half Key" Length used for Balancing Rotor

A = ____________________

a = Depth of Keyway in Shaft

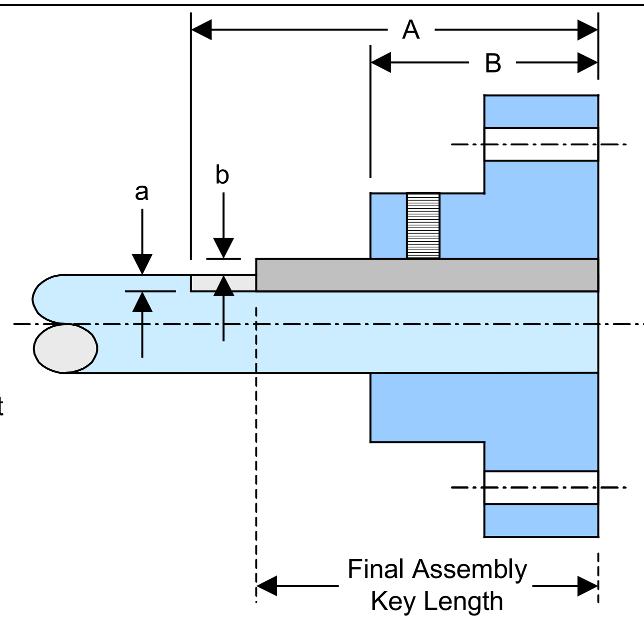
a = ____________________

B = "Half Key" Length used for Balancing Coupling

B = ____________________

b = Depth of Keyway in Coupling

b = ____________________



$$\text{Final Assembly Key Length} = \frac{(A \times a)+(B \times b)}{a+b}$$

Final Assembly Key Length = ___________

Rotor Assembly S/N or other ID# ____

Fitment S/N or other ID# ____

Figure 8 Balance Test Key Dimensions for Steel Key and Coupling

7.10 RESONANCE

If the frequency of any harmonic component of a periodic forcing phenomenon is equal to or approximates the frequency of any mode of a machine's natural frequency of vibration, a condition of resonance might exist. Operating speeds must have a separation margin (SM) of at least 25% of the resonance speed (Ω_o). Where multiple resonances exist, the operating speed shall also be above or below any given resonance and removed from the resonance by a separation margin of at least 25% of the resonance speed (Reference Figure 9).

TOC

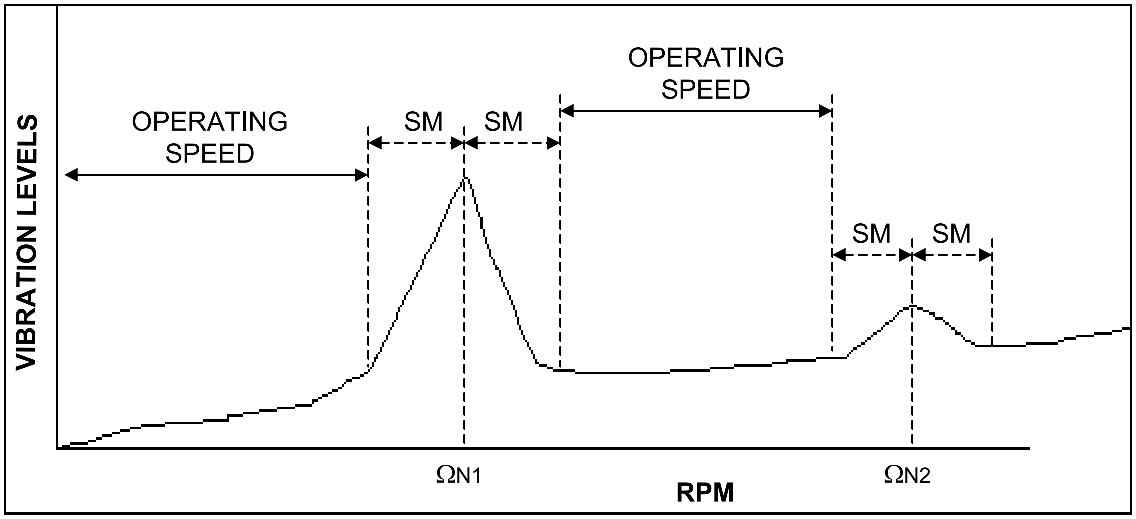


Figure 9 Resonance Separation Margin (SM)

8.0 MACHINE QUOTATION, CERTIFICATION, AND ACCEPTANCE

8.1 QUOTATION

8.1.1 The Quotation shall specify that the equipment will meet the applicable vibration level limits in Section 9 of this Specification - or the vibration level limits (if different from GM Specification V1.0 - Latest Version) specified by the purchaser in the "Request for Quote".

8.1.2 The Quotation shall state the applicable specification vibration level limits being requested.

8.1.3 Any additional costs required to meet the specification limits shall be grouped in a separate section of the Quotation and titled "VIBRATION LIMITS". Costs must be itemized and sufficiently detailed to permit a complete evaluation by the purchaser.

8.2 MEASUREMENT REQUIREMENTS FOR MACHINE CERTIFICATION

8.2.1 Vibration measurements shall:

8.2.1.1 Be presented in the format specified in Section 4 of this document.

8.2.1.2 Be the responsibility of the supplier unless specified otherwise by the purchaser.

8.2.1.3 Be performed by technically qualified person, who is trained and experienced in vibration measurement. This person must, at a minimum, be Certified as a Vibration Specialist I by the Vibration Institute (or equivalent). A resume' of the technical qualifications and a copy of the Vibration Institute certification of the person doing the machine vibration certification shall be submitted as a part of the machine vibration certification data.

8.2.1.4 Be taken with the machine operating as specified in Section 9 Where *no load* is specified, no actual machining such as cutting, grinding, etc. is to be taking place during collection of machine vibration data. Where *rated load* is specified, rated operating load--either actual or simulated--will be applied during collection of machine vibration data.

8.2.1.5 Prior to taking vibration measurements, the machine will be *run-in* until it reaches speed and thermal stability.

TOC

8.2.2 Vibration Signatures as required by Section 9 of this specification, shall be submitted to the purchaser's Maintenance Department or other authorized representative before acceptance of the machinery or equipment being purchased will be authorized.

8.2.3 Vibration data for machine certification shall be measured during *run-off* at the vendor's facility. Where it is impractical to set-up and test a complete machine at the vendor's facility, arrangements shall be made to perform the test at the purchaser's facility. Under this circumstance, shipment of the equipment does not relieve the vendor of the responsibility for meeting the specified vibration level limits.

8.2.4 The purchaser shall have the option to verify vibration data of equipment during machine *run-off* at the vendor's test site prior to shipment, or at the plant site per Section 8.2.3, prior to final acceptance authorization.

8.2.5 The machine layout drawing shall be submitted as a part of the Machine Vibration Certification. Vibration measurement locations on the machine's surface at which vibration measurements are taken shall be designated on the drawing per Sections 4.0 and 5.0 requirements. At the option of the purchaser, shaft speeds, gear type and number of gear teeth, gear mesh frequencies, bearing manufacturer's name, bearing type number and class, shall be identified on the machine layout drawing. Where gearboxes are involved, an insert such as illustrated in Figure 6C shall be included on the machine layout drawing.

8.3 ACCEPTANCE

Authorization for machine/equipment acceptance based on the vibration limits of this specification requires signature by the purchaser's authorized representative. A copy of the acceptance must be sent to the plant's purchasing department before final acceptance is authorized.

9.0 VIBRATION LEVEL LIMITS - COMPONENTS

9.1 ELECTRIC MOTORS -- Refer to Section 9.1 "GM Vibration Standards for Electric Motors".

9.2 MACHINE TOOL SPINDLES AND HEADS -- Refer to Section 9.2 "GM Vibration Standards for Machine Tool Spindles and Heads".

9.3 FANS -- Refer to Section 9.3 "GM Vibration Standards for Fans".

9.4 PUMPS -- Refer to Section 9.4 "GM Vibration Standards for Pumps".

9.5 GEARBOXES -- Refer to Section 9.5 "GM Vibration Standards for Gearboxes".

9.6 DEFAULT VIBRATION LEVEL LIMITS -- Refer to Section 9.6 "GM Vibration Standard Default Limits".

10.0 VIBRATION LEVEL LIMITS - COMPLETE MACHINE ASSEMBLY

A complete machine is defined as the entire assembly of components, sub-components, and structure, which is purchased to perform a specific task(s). **On a Complete Machine Assembly with all individual components operating in their normal operating condition, mode, and sequence, the Component Vibration Level Limits for the complete machine acceptance are the same as when the component is tested individually.** Where assembled component levels exceed the acceptable limits, the cause will be identified, if possible, and a decision to correct or accept mutually agreed upon by purchaser and machine builder.

TOC

SECTION 9.1

GM VIBRATION STANDARDS FOR ELECTRIC MOTORS

9.1.1 ELECTRICAL MOTOR MEASUREMENT REQUIREMENTS

It is the purpose of this specification to state specifically how to check vibration on all completely assembled motors and generators. For brevity, the word "motor" will be used hereinafter to mean motors and/or generators.

9.1.1.1 Motors will be defined by three (3) categories:
Standard motor.......Utility Operations
Special motor........Semi-Finish Operations
Precision motor......Finish Operations

9.1.1.2 The frequency range for motor certification will be from F_{min} = 0.3 X Running Speed (synchronous speed) to F_{max} = 2,000 Hertz (120,000 CPM) for velocity and to F_{max} = 5,000 Hertz (300,000 CPM) for acceleration.

9.1.1.3 Alternating current (AC) motors will be tested at rated voltage and frequency, and no load. Single speed alternating current motors will be tested at synchronous speed. A multispeed alternating current motor will be tested at all its rated synchronous speeds. AC motors with Variable Frequency Drives (VFD) and Direct current (DC) motors will be tested at their highest rated speed. Series and universal motors will be tested at operating speed.

9.1.1.4 New and rebuilt motors shall be tested in accordance with the following:

9.1.1.4.1 Place the motor (and steel base plate if necessary) on a resilient mounting so proportioned that the up and down natural frequency shall be at least as low as 25 percent of the test speed of the motor. [The static load deflection due to the motor and the steel base plate must be equal to or greater than the amounts shown in Table 9.1] The compression of the resilient mounting shall in no case be more than 50 percent of the original thickness of the resilient pad.

9.1.1.4.2 Where vibration measurements are taken with the machine is mounted on a foundation, the natural frequency of mounted machine and foundation shall be removed by at least 25 percent from the rotational exciting frequency.

9.1.1.5 Motors designed to be mounted vertically should be tested in a *cradle*, designed to mount the motor in its designated vertical mount orientation. Care must be taken that the cradle mount provides a stable and **SAFE** test environment.

9.1.1.6 To support flange-mounting motors, it will be necessary to use a cradle. In this case, the cradle plus the steel plate must weigh less than 1/20 the weight of the motor.

9.1.2 MOTOR ISOLATION

9.1.2.1 Support Pad: For consistent results, the support pad with mounted motor (and plate if necessary), must have an up and down natural frequency less than one-quarter (25%) the speed of the motor.

9.1.2.2 Plate: A steel base plate must be used between the motor and the support pad.*

1. The plate must weigh less than 1/20 the weight of the motor.
2. Care must be taken that the motor does not rock on the plate ("Softfoot" must be removed).
3. The linear dimensions of the plate shall not exceed those of the projected motor base by more than 10%.

* To test motors that are to be resilient mounted upon installation, omit the steel base plate and put the base of the motor directly on the resilient support test pad.

TOC

9.1.2.3 Resilient (Rubber or "rubber like") Support Pad: - Support the motor and steel base plate on a resilient pad per the following specifications:

Pad thickness shall be such that the downward deflection of the pad due to the static load weight of the motor and plate will be equal to or greater than that shown in the following table, but must in no case be more than 1/2 the original thickness of the pad.

TABLE 9.1

MOTOR SYNCHRONOUS SPEED	*ISOLATION PAD MINIMUM COMPRESSION*	
(RPM)	*MILLIMETERS*	*(INCHES)*
600	*58*	*(2-1/4)*
720	*40*	*(1-9/16)*
750	*38*	*(1-15/32)*
800	*33*	*(1-17/64)*
900	*26*	*(1.00)*
1000	*21*	*(13/16)*
1200	*15*	*(9/16)*
1500	*10*	*(3/8)*
1800	*7*	*(1/4)*
2400	*4*	*(9/64)*
3000	*3*	*(3/32)*
3600	*2*	*(1/16)*
7200	*1*	*(1/64)*

NOTE: The required deflection is inversely proportional to the square of the speed.
The RPM's listed in Table 9.1 is that at which the motor is run during vibration test.

For any speed not listed in Table 9.1, use the following formula:

Deflection (millimeters) = $25.4 \times [900/(RPM)]^2$ Deflection (inches) = $[900/(RPM)]^2$

- The resilient support pad SHALL support the entire base plate area. The pad shall not be more than 10% larger than the base plate.
- For any motor to be tested, the necessary thickness of the resilient pad can be calculated from the following formula:

T = KDA/F where T = pad thickness (inches)
K = modulus of elasticity (lbs. per sq. in.)
D = deflection required (inches)
A = area of contact between rubber pad and motor base or steel plate (sq. inch)
F = weight of motor and plate (lbs.)

To obtain pad thickness in millimeters, multiply by 25.4 mm/inch

TOC

9.1.3 PREPARATION FOR TESTING and SAFETY

- Use a test table or other horizontal surface free from vibration.
- Place the proper flexible pad on the test table or horizontal surface and the proper plate on the pad.
- Place the motor squarely on the plate so that it is reasonably level [i.e. all four corners of the base or plate are the same height above the table ±4 mm (± 1/8 inch)].
- Unless otherwise specified, fit the shaft keyway with half of a standard key (i.e. full length and flush with the top of the keyway).
- To avoid the possibility of bending the shaft, use a half key, which is 0.005 mm (0.0002 inch) less in width than the keyway, and is held, in place with tape or by other suitable means.
- Large motors should be steadied during startup with a hoist sling or by other suitable means, to avoid the danger of their being overturned.

9.1.4 CRITICAL SPEED

Completely assembled motors shall have a percentage separation between the rotor shaft first actual critical speed and the rated motor speed as specified:

ROTOR DESIGN	FIRST ACTUAL CRITICAL SPEED LOCATION
Rigid Shaft	At least 25% Above Rated Motor Speed
Semi Flexible Shaft	Maximum of 85 % of Motor Speed
Flexible Shaft	2^{nd} Critical Speed

9.1.5 LIMITS

9.1.5.1 AC/DC Motors:

Electrical motors shall meet the following requirements:

9.1.5.1.1 The Velocity Amplitude of any line of resolution, measured at all bearing positions in any direction radial or axial shall not exceed the Line-Amplitude Band Limit values specified in Table 9.1A and graphed in Figure 9.1.

9.1.5.1.2 The Acceleration Overall Amplitude measured at all bearing positions in any direction radial or axial shall not exceed the Band-Limited Overall Amplitude Acceptance Limit values specified in Table 9.1A and graphed in Figure 9.1 when determined in accordance with Sections 7.2 and 7.3 using the frequency range defined in Section 9.1.1.2

TOC

TABLE 9.1A MAXIMUM ALLOWABLE VIBRATION LEVELS FOR ELECTRIC MOTORS				
VELOCITY LINE-AMPLITUDE BAND LIMITS				
BAND	FREQUENCY RANGE Hz (CPM)	**STANDARD** MM/SEC - RMS (INCH/SEC - PEAK)	**SPECIAL** MM/SEC RMS (INCH/SEC - PEAK)	**PRECISION** MM/SEC RMS (INCH/SEC - PEAK)
1	[0.3 →0.8] x RPM	0.718 (0.04)	0.718 (0.04)	0.36 (0.02)
2	[0.8→1.2] x RPM	1.35 (0.075)	0.718 (0.04)	0.36 (0.02)
3	[1.2→3.5] x RPM	0.718 (0.04)	0.718 (0.04)	0.18 (0.01)
4	[3.5→8.5] x RPM	0.54 (0.03)	0.54 (0.03)	0.18 (0.01)
5	8.5 x RPM→1,000 Hz (60,000 CPM)	0.54 (0.03)	0.54 (0.03)	0.09 (0.005)
6	[1,000 → 2,000] Hz (60,000 → 120,000) CPM)	0.54 (0.03)	0.54 (0.03)	0.09 (0.005)
ACCELERATION BAND-LIMITED OVERALL AMPLITUDE LIMITS				
BAND	FREQUENCY RANGE Hz (CPM)	**STANDARD** g's RMS (g's PEAK)	**SPECIAL** g's RMS (g's PEAK)	**PRECISION** g's RMS (g's PEAK)
1	0.3 x RPM → 5K Hz (300K CPM)	0.35 (0.5)	0.35 (0.5)	0.176 (0.25)

9.1.6 ELECTRICAL MOTOR CERTIFICATION

9.1.6.1 The maximum Line Amplitude of vibration in each Band at all bearing positions in any direction (radial and axial) as required by Table 9.1A shall be listed in tabular form.

9.1.6.2 The maximum Band Limited Overall Amplitude of vibration at all bearing positions in any direction (radial and axial) as required by Table 9.1A shall be listed in tabular form.

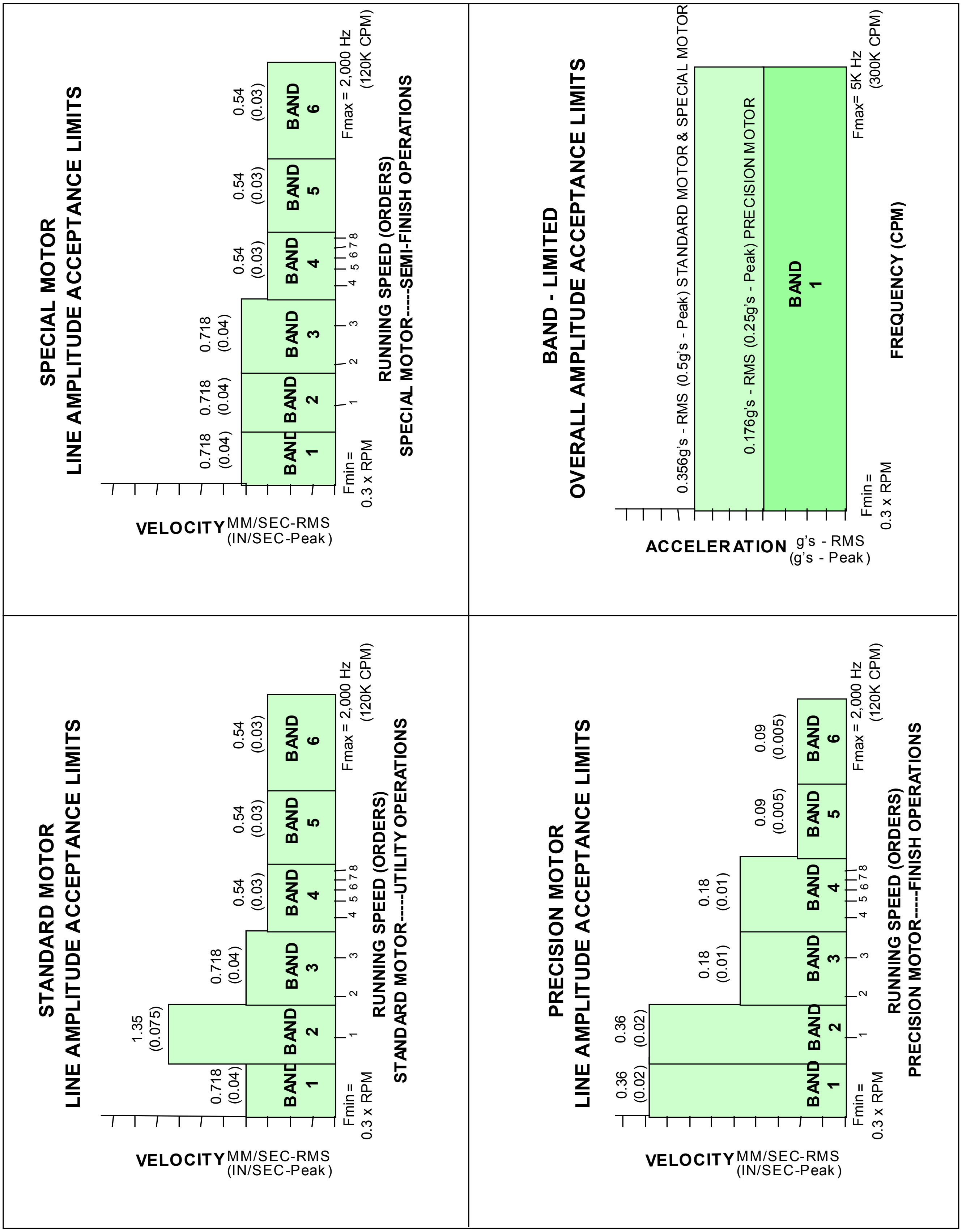
9.1.6.3 Vibration signatures of velocity and acceleration for Radial vibration measurements taken at Position 001 @ 0^o and 90^o, Position 002 @ 0^o and 90^o, and Position 002 Axial shall be submitted as part of the motor certification. If due to machine mounting radial vibration readings at 0^o and 90^o are not accessible, then two accessible radial readings 90^o apart shall be taken at Positions 001 and 002. Data shall be identified with the Motor Serial Number, Frame Number, Model Number, Horsepower, and Synchronous speed.

9.1.6.4 The motor nameplate shall carry the following designation:

FOR STANDARD	"1.35 MM/SEC RMS (0.075 IN/S Peak) @ 1X"
FOR SPECIAL	"0.718 MM/SEC RMS (0.04 IN/S Peak) @ 1X"
FOR PRECISION	"0.36 MM/SEC RMS (0.02 IN/S Peak) @ 1X"

9.1.6.5 Vibration data and signatures must be submitted with the motor to the purchaser's Maintenance Department or other authorized representative before acceptance of the motor will be authorized.

TOC


SPECIAL MOTOR
LINE AMPLITUDE ACCEPTANCE LIMITS
VELOCITY MM/SEC-RMS (IN/SEC-Peak)
0.718 (0.04)
0.718 (0.04)
0.718 (0.04)
0.54 (0.03)
0.54 (0.03)
0.54 (0.03)
BAND 1
BAND 2
BAND 3
BAND 4
BAND 5
BAND 6
Fmin = 0.3 x RPM
1 2 3 4 5 6 7 8
Fmax = 2,000 Hz (120K CPM)
RUNNING SPEED (ORDERS)
SPECIAL MOTOR-----SEMI-FINISH OPERATIONS
BAND - LIMITED
OVERALL AMPLITUDE ACCEPTANCE LIMITS
ACCELERATION g's - RMS (g's - Peak)
0.356g's - RMS (0.5g's - Peak) STANDARD MOTOR & SPECIAL MOTOR
0.176g's - RMS (0.25g's - Peak) PRECISION MOTOR
BAND 1
Fmin = 0.3 x RPM
Fmax= 5K Hz (300K CPM)
FREQUENCY (CPM)
STANDARD MOTOR
LINE AMPLITUDE ACCEPTANCE LIMITS
VELOCITY MM/SEC-RMS (IN/SEC-Peak)
0.718 (0.04)
1.35 (0.075)
0.718 (0.04)
0.54 (0.03)
0.54 (0.03)
0.54 (0.03)
BAND 1
BAND 2
BAND 3
BAND 4
BAND 5
BAND 6
Fmin = 0.3 x RPM
1 2 3 4 5 6 7 8
Fmax = 2,000 Hz (120K CPM)
RUNNING SPEED (ORDERS)
STANDARD MOTOR-----UTILITY OPERATIONS
PRECISION MOTOR
LINE AMPLITUDE ACCEPTANCE LIMITS
VELOCITY MM/SEC-RMS (IN/SEC-Peak)
0.36 (0.02)
0.36 (0.02)
0.18 (0.01)
0.18 (0.01)
0.09 (0.005)
0.09 (0.005)
BAND 1
BAND 2
BAND 3
BAND 4
BAND 5
BAND 6
Fmin = 0.3 x RPM
1 2 3 4 5 6 7 8
Fmax = 2,000 Hz (120K CPM)
RUNNING SPEED (ORDERS)
PRECISION MOTOR-----FINISH OPERATIONS

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SECTION 9.2

GM VIBRATION STANDARDS

FOR MACHINE TOOL SPINDLES AND HEADS

9.2.1 SPINDLE AND HEAD REQUIREMENTS

9.2.1.1 All single spindle and multi-spindle units will be (where possible) mounted on a test stand in their normal operating attitude, properly secured in a STRESS FREE CONDITION and be either direct coupled or belt driven. Integral motor spindles (motorized spindles) will be tested as a self-powered unit.

9.2.1.2 The Spindle or Head will be run-in until it reaches temperature stability at operating speed.

9.2.1.3 **Measurement Locations:**

Vibration measurement locations shall be;

- in accordance with Sections 5.0 and 6.0.
- at a point as close to the spindle bearing as possible and in line with the spindle center line (Ref. Figures 9.2.1A, B, & C).

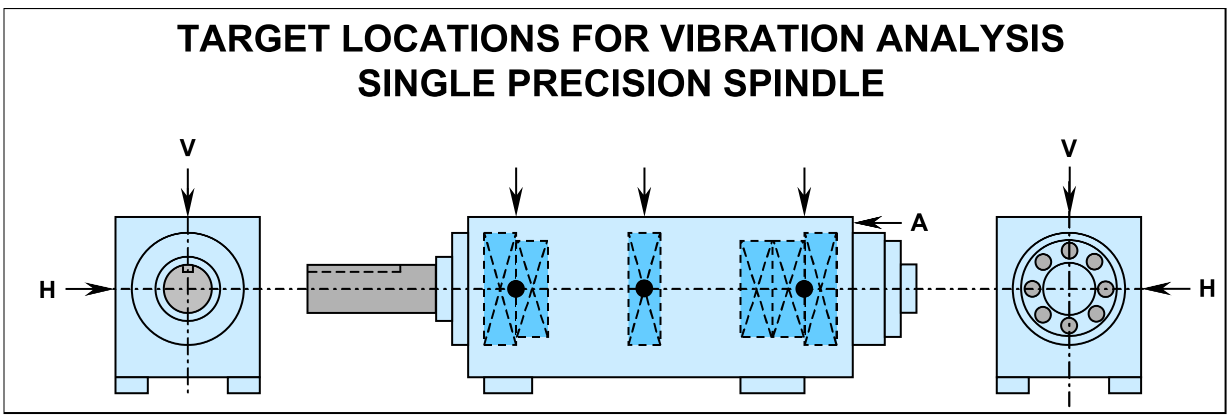

Figure 9.2.1A Measurement Locations for Single Precision Spindle

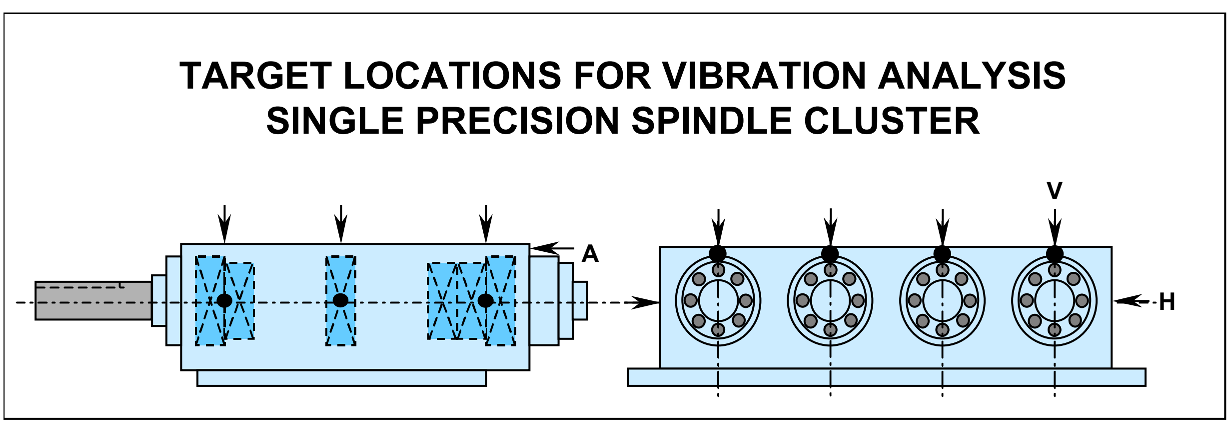

Figure 9.2.1B Measurement Locations for Spindle Cluster

TOC

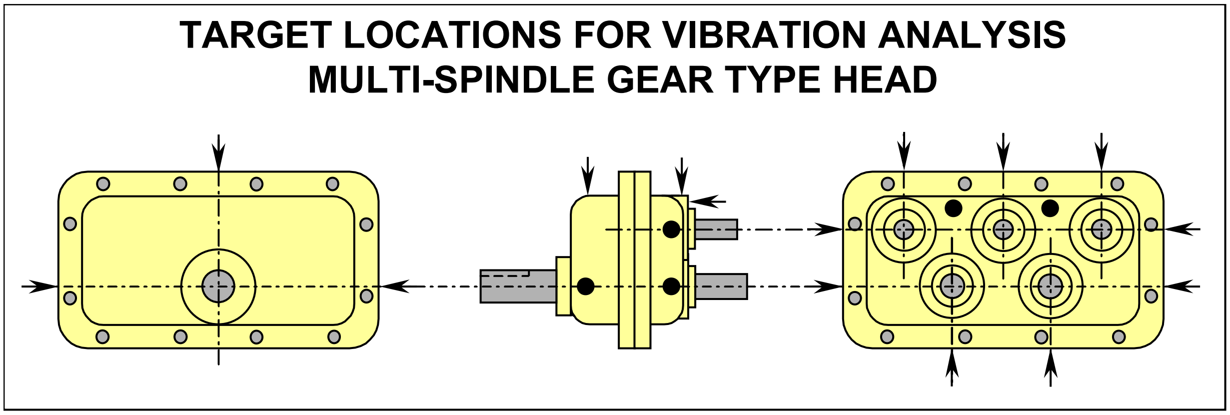

Figure 9.2.1C Measurement Locations for Multi-Spindle Gear-type Head

9.2.1.4 Operating Speed:

9.2.1.4.1 If a spindle unit is designed to operate at one speed, the unit is to be tested at that speed.

9.2.1.4.2 If a spindle unit is designed to operate at multiple speeds, the unit is to be tested at each rated speed.

9.2.1.4.3 If a spindle unit is designed to operate at all speeds in a given speed range, the unit must be tested at its' maximum rated speed, unless this coincides with a resonance or resonance-like condition. In this case, the test speed shall be the maximum speed possible without encountering the resonance or resonance-like condition.

9.2.2 VIBRATION LIMITS

9.2.2.1 Limits For Box and Cartridge-Type Spindles:

9.2.2.1.1 The maximum velocity amplitude of vibration at bearing locations in any direction Radial or Axial shall not exceed the Line Amplitude Band Limit values specified in Table 9.2A and Table 9.2B, and graphed in Figure 9.2.2 or Figure 9.2.4.

9.2.2.1.2 The maximum acceleration amplitude of vibration at bearing locations in any direction Radial or Axial shall not exceed the Band-Limited Overall Amplitude Acceptance Limits specified in Table 9.2A and Table 9.2B, and graphed in Figure 9.2.3 or Figure 9.2.5.

TABLE 9.2A MAXIMUM ALLOWABLE VIBRATION LEVELS FOR GEARLESS TYPE SPINDLES
600 TO 12,000 RPM (<= 400,000 DN)

LINE-AMPLITUDE BAND LIMITS

BAND	FREQUENCY RANGE Hz (CPM)		VELOCITY MM/SEC RMS	(INCH/SEC - PEAK)
1	[0.3 → 0.8] x RPM		0.18	(0.01)
2	[0.8 → 1.2] x RPM		0.18	(0.01)
3	[1.2 → 3.5] x RPM		0.18	(0.01)
4	3.5 x RPM → 2,000 Hz (120,000 CPM)	Angular Contact Bearings Roller Bearings	0.09 0.135	(0.005) (0.0075)

BAND-LIMITED OVERALL AMPLITUDE LIMITS

BAND	FREQUENCY RANGE Hz (CPM)		ACCELERATION g's RMS	(g's PEAK)
1	0.3 x RPM →10,000 Hz (600K CPM)	Angular Contact Bearings Roller Bearings ≤ 1,000 RPM Roller Bearings > 1,000 RPM	0.35 0.71 1.06	(0.5) (1.0) (1.5)

TOC

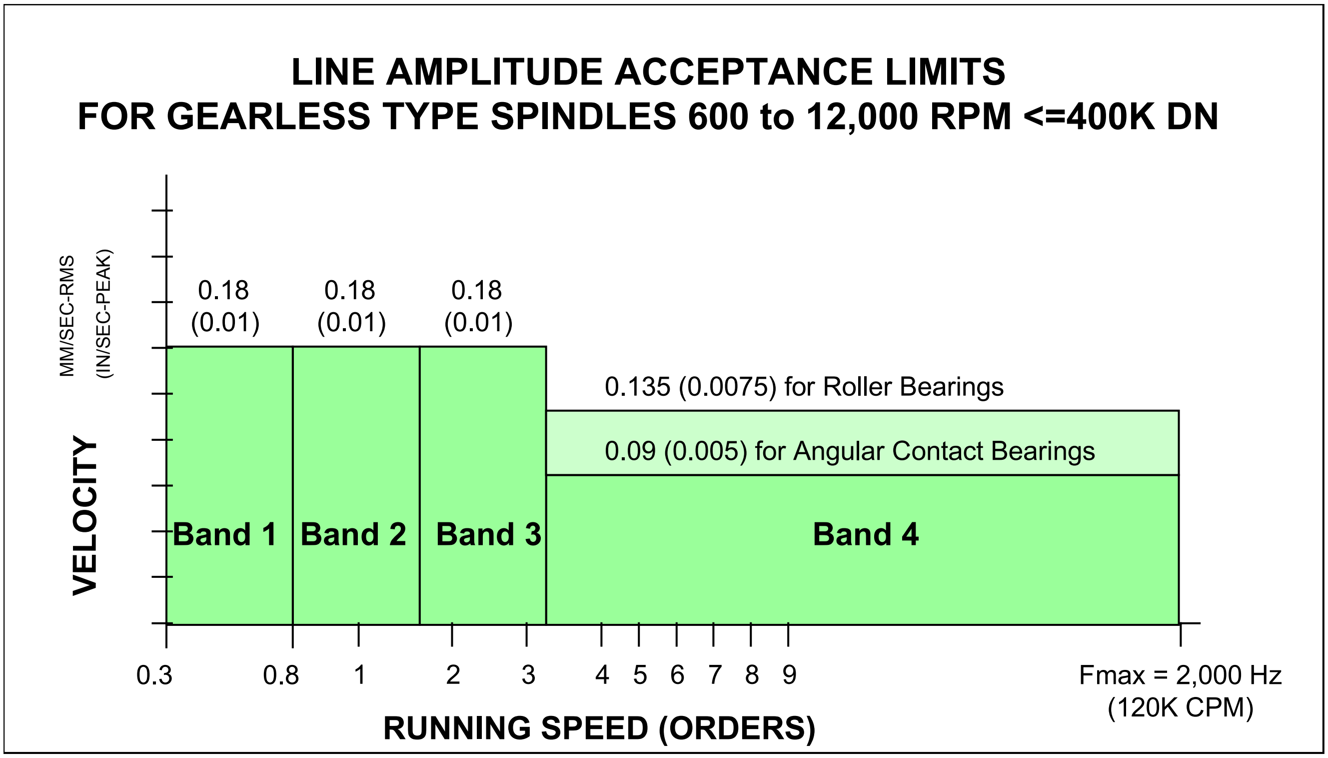

Figure 9.2.2 Line Amplitude Acceptance Limits for Gearless Type Spindles 600 to 12,000 RPM

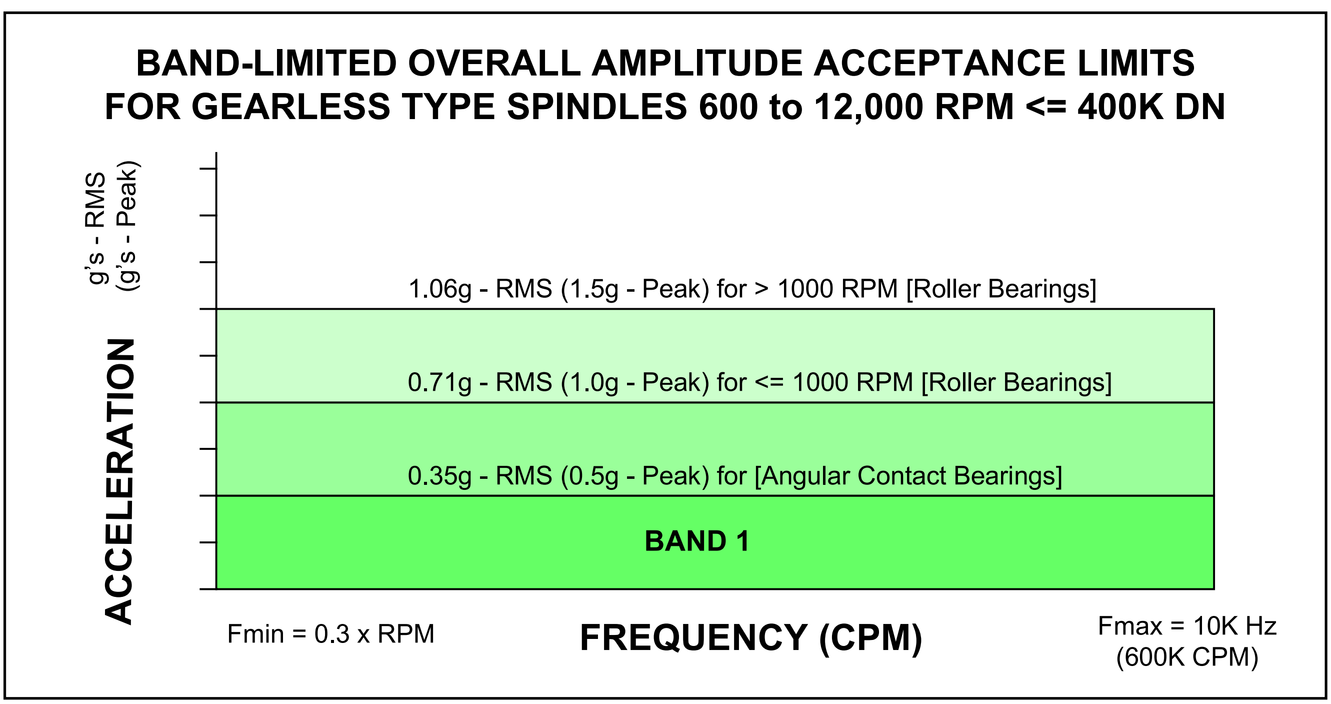

Figure 9.2.3 Band-Limited Overall Amplitude Acceptance Limits for Gearless Type Spindles 600 to 12,000 RPM

TABLE 9.2B MAXIMUM ALLOWABLE VIBRATION LEVELS FOR GEARLESS TYPE SPINDLES <600 RPM				
LINE-AMPLITUDE BAND LIMITS				
BAND	FREQUENCY RANGE Hz (CPM)		DISPLACEMENT [Peak - to - Peak] MICROMETER	(MILS)
1	[0.3 → 0.8] x RPM		2.54	(0.1)
2	[0.8 → 1.2] x RPM		2.54	(0.1)
			VELOCITY MM/SEC RMS	(INCH/SEC - PEAK)
3	[1.2 → 3.5] x RPM		0.18	(0.01)
4	3.5 x RPM → 1,000 Hz (60K CPM)	Angular Contact Bearings	0.09	(0.005)
		Roller Bearings	0.135	(0.0075)
BAND-LIMITED OVERALL AMPLITUDE LIMITS				
BAND	FREQUENCY RANGE Hz (CPM)		ACCELERATION g's RMS	(g's PEAK)
1	0.3 x RPM → 1,000 Hz (60K CPM)	Angular Contact Bearings	0.35	(0.5)
		Roller Bearings	0.53	(0.75)

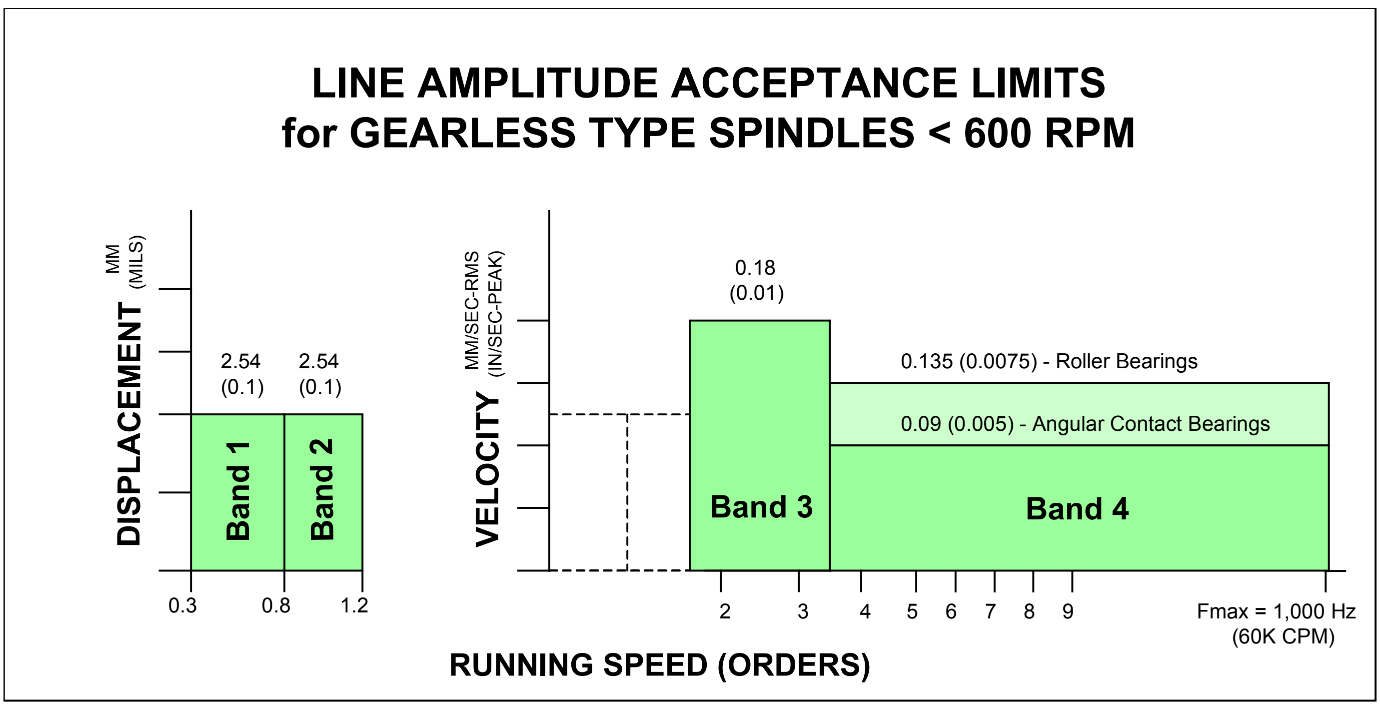

Figure 9.2.4 Line Amplitude Acceptance Limits for Gearless Type Spindles <600 RPM

TOC

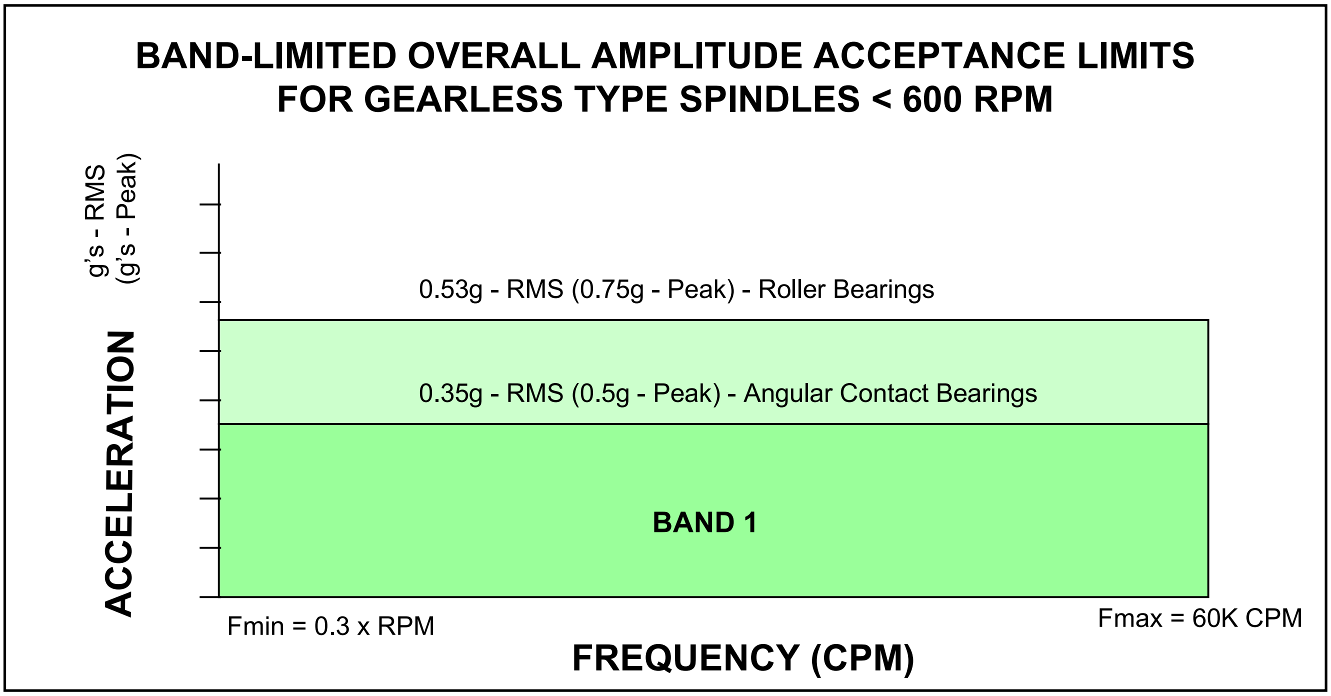

Figure 9.2.5 Band-Limited Overall Amplitude Acceptance Limits for Gearless Type Spindles <600 RPM

9.2.2.2 Limits for Motorized Spindles:

9.2.2.2.1 The complete assembly must meet the vibration limits specified in Section 9.2.2.1 "LIMITS FOR BOX AND CARTRIDGE-TYPE SPINDLES".

9.2.2.3 Limits for Multi-spindle (Clusters) Non-Gear Type Assemblies:

9.2.2.3.1 Belt driven Multi-Spindle Clusters (Reference Figure 9.2.1B) shall be tested as a complete assembly.

9.2.2.3.2 The complete assembly must meet the vibration limits specified in Section 9.2.2.1 "LIMITS FOR BOX AND CARTRIDGE-TYPE SPINDLES"

9.2.2.4 Limits for Gear Driven Spindle Assemblies:

9.2.2.4.1 For gear driven spindle assemblies the frequency range of measurement shall be from 0.3 x lowest shaft running speed to 3.5 x highest Gear Mesh Frequency (GMF) unless otherwise specified. The number of lines of resolution shall be sufficient to resolve the 1 x lowest shaft speed sidebands at GMF.

9.2.2.4.2 In the velocity spectra and the acceleration spectra, the line amplitude of the Gear Mesh Frequency sidebands must be less than (<) 0.5 times the line amplitude of the Gear Mesh Frequency. The line amplitude of sidebands of harmonics of the Gear Mesh Frequency must also be <.5 X the line amplitude of the GMF harmonics.

9.2.2.4.3 In the velocity spectra the line amplitude of GMF harmonics must not exceed 0.2 x GMF line amplitude.

TOC

9.2.2.4.4 The maximum velocity band-limited overall amplitude (Inch/sec - Peak) of vibration at locations specified in 9.2.1.3 and illustrated in Figure 9.2.1C, in any direction (as defined in Section 4) shall not exceed the Band-Limited Overall Amplitude Acceptance Limits specified in Table 9.2C and graphed in Figure 9.2.6 when determined in accordance with Section 7.2.2.

TABLE 9.2C MAXIMUM ALLOWABLE VIBRATION LEVELS FOR GEAR-DRIVEN SPINDLE ASSEMBLIES		
BAND-LIMITED OVERALL AMPLITUDE LIMITS		
BAND	FREQUENCY RANGE Hz (CPM)	VELOCITY MM/SEC RMS (INCH/SEC - PEAK)
1	0.3 x Lowest Shaft RPM to 3.5 x Highest GMF	1.4 (0.08)

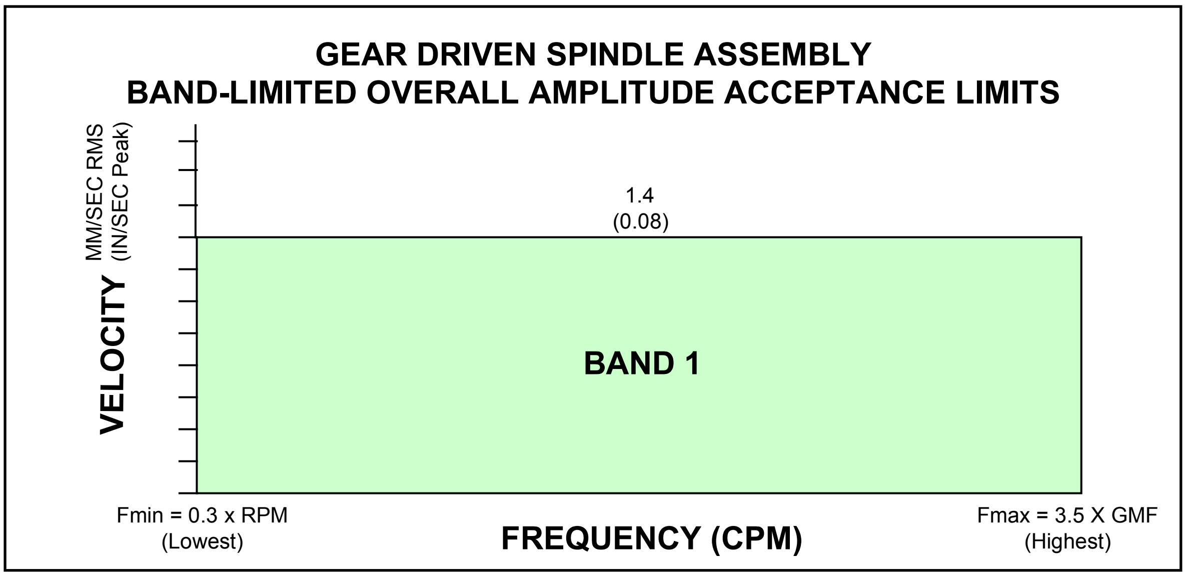

Figure 9.2.6 Band-Limited Overall Amplitude Acceptance Limits for Gear-Driven Spindle Assemblies

9.2.2.4.5 Where the number of machining components or high speeds cause a gear driven spindle assembly to exceed acceptable limits, a decision to correct or accept shall be mutually agreed upon by purchaser and machine builder.

9.2.3 SPINDLE CERTIFICATION

9.2.3.1 The maximum Line Amplitude of vibration in each Band at all bearing positions in any direction (radial and axial) as required by Table 9.2A, or 9.2B shall be listed in tabular form.

9.2.3.2 The maximum Band Limited Overall Amplitude of vibration at all bearing positions in any direction (radial and axial) as required by Table 9.2A, 9.1B, or 9.2C shall be listed in tabular form.

9.2.3.3 Vibration signatures of velocity and acceleration for Radial vibration measurements taken at 0^o and 90^o, at each bearing Position and one (1) Axial Position shall be submitted as part of the spindle certification. If at any bearing Position, due to machine mounting constraints, radial vibration readings at 0^o and 90^o are not accessible, then two accessible radial readings 90^o apart shall be taken at said Position.

9.2.3.4 Vibration data and signatures must be submitted with the motor to the purchaser's Maintenance Department or other authorized representative before acceptance of the spindle/machine will be authorized.

TOC

9.2.4 BALANCE LIMITS FOR SPINDLE COMPONENTS

9.2.4.1 Any spindle component that rotates with the spindle (e.g. tooling, tool holder, sheave, chuck, fixture, actuator, etc.) to be mounted on a spindle, shall be balanced to an ISO Balance Quality Grade (G) that is equal to or less-than that for that spindle. [ISO Balance Quality Grade (G) for the spindle to be obtained from the spindle manufacturer].

9.2.4.2 If the ISO Balance Quality Grade of the spindle is not known, the spindle component shall be balanced to an ISO Grade 0.4 or less. (ISO G = 0.4 is the recommended balance quality grade for spindles).

9.2.4.3 Any spindle component, when fastened to the spindle, and rotated at running speed, shall not increase the vibration readings taken on the spindle above those specified in Figures 9.2.2, 9.2.3, 9.2.4, 9.2.5, or 9.2.6, and Tables 9.2A, 9.2B, or 9.2C.

9.2.4.4 **Variable Diameter Tooling:**

9.2.4.4.1 A variable diameter tool holder shall always be balanced to an ISO Balance Quality Grade (G) that is equal to or less-than that specified for the spindle that it is used on. This balancing requirement applies at all machining positions, as well as when the tool is rotating in any idle or retracted position.

9.2.4.4.2 If the spindle's balance grade is not known, then the ISO Grade G 0.4 will be used.

9.2.4.4.3 Any tooling/tool holder whose position and/or rotational diameter changes during the machine cycle, when fastened to the spindle, and rotated at running speed, shall not increase the vibration readings taken on the spindle above those specified in Figures 9.2.2, 9.2.3, 9.2.4, 9.2.5, or 9.2.6, and Tables 9.2A, 9.2B, or 9.2C.

9.2.4.5 **Rotating Chucks or Fixtures with Parts:**

9.2.4.5.1 If the spindle's balance grade is not known, then the chuck or fixture shall be balanced to ISO Grade G 0.4

9.2.4.5.2 Rotating part holders (Chucks or Fixtures) shall be balanced so that the spindle's vibration readings do not increase above those shown in Figures 9.2.2, 9.2.3, 9.2.4, 9.2.5, or 9.2.6, and Tables 9.2A, 9.2B, or 9.2C when turned with part at running speed.

TOC

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SECTION 9.3

GM VIBRATION STANDARDS

FOR FANS

9.3.1 FANS ARE DEFINED AS:

All non-positive displacement air handling units including Induced Draft (ID) Fans, Forced Draft (FD) Fans, Overhung Fans, Centerhung Fans, Centrifugal, Vaneaxial, Tubeaxial, Blowers, etc.

9.3.2 BALANCING

9.3.2.1 Permanently attached balancing weights must be secured by welding, bolting, pop-riveting, or of a *clip-on* design.

- If bolted, a hardened bolt must be used in conjunction with a mechanical locking device (e.g. lockwasher or locknut).
- *Clip-on* balancing weights can only be used on centrifugal type fans and must be located and attached on the ID pitch of the blades such that the rotational motion of the fan creates positive seating of the *clip-on* weight against the fan blade.
- Balancing weights and method of attachment must be stable at fan operating temperature, and of a material compatible with the parent material of the fan to which the balancing weight is attached.

NOTE: The use of *stick-on* weights or lead weights is not acceptable.

9.3.2.2 Any parent metal removed to achieve dynamic or static balance shall be drilled out in a manner, which will maintain the structural integrity of the rotor or sheave.

9.3.2.3 Access to the fan rotor for field balancing shall be designed into the system.

NOTE: It is recommended that components (rotor, shaft, and sheave) are balanced individually and then trim balanced as a total assembly.

9.3.3 SHAFT TOLERANCE

Fan shaft diameter shall meet bearing manufacturer specifications for ground shaft tolerances.

9.3.4 RESONANCE

Natural frequencies of the completely assembled fan unit shall not be excited at the operating speed. (Running speed should be at least 25% removed from a natural frequency of the system).

9.3.5 LIMITS

Fans shall be tested under installation mounting conditions. If such conditions are unknown, then the fan shall be Tested using isolation mounting per the requirements set forth in Section 9.1 on Motors. If spring-mounted tolerance limits increase +50 per cent at rotating speed of the fan.

9.3.5.1 New and Rebuilt/Repaired Fans shall conform to the vibration limits specified in Table 9.3 when operating at specified system CFM and Fan Static Pressure.

9.3.5.2 The frequency range for fan certification shall be from F_{min} = 0.3 X Running Speed of Fan to 2,000 Hertz (120,000 CPM) for velocity and to 5,000 Hertz (300,000 CPM) for acceleration.

TOC

9.3.5.3 For fan speeds up to 3600 RPM, the maximum velocity amplitude of vibration at all bearing positions in any direction radial or axial shall not exceed the Line Amplitude Band Limit values specified in Table 9.3 and graphed in Figure 9.3.

9.3.5.4 For fan speeds up to 3600 RPM, the Band-Limited Overall vibration level of acceleration at all bearing locations in any direction radial or axial shall not exceed the Band-Limited Overall Amplitude Acceptance Limit values specified in Table 9.3 and graphed in Figure 9.3.2.

9.3.5.5 Acceptance limits for fans running over 3600 RPM shall be specified by the purchaser.

TABLE 9.3 MAXIMUM ALLOWABLE VIBRATION LEVELS FOR FANS			
BAND	FREQUENCY RANGE Hz (CPM)	VELOCITY LINE AMPLITUDE BAND LIMITS MM/SEC RMS	(INCH/SEC - PEAK)
1	[0.3 → 0.8] x RPM	0.718	(0.04)
2	[0.8 → 1.2] x RPM	1.35	(0.075)
3	[1.2 → 3.5] x RPM	0.718	(0.04)
4	3.5 x RPM → Fmax = 2,000 Hz (120,000 CPM)	0.54	(0.03)
		ACCELERATION BAND LIMITED OVERALL AMPLITUDE D LIMITS g's RMS	(g's PEAK)
1	0.3 x RPM → Fmax = 5,000 Hz (300,000 CPM)	0.35	(0.5)

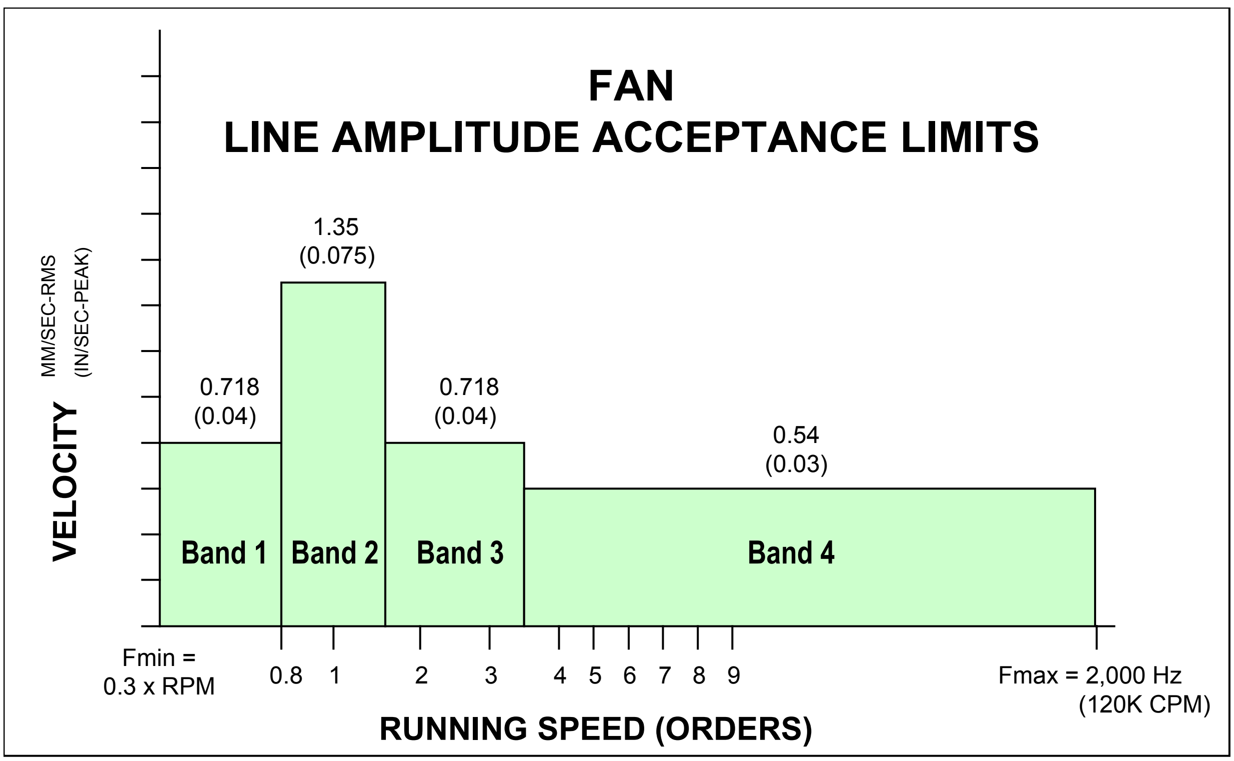

Figure 9.3.1 Line Amplitude Acceptance Limits for Fans

TOC

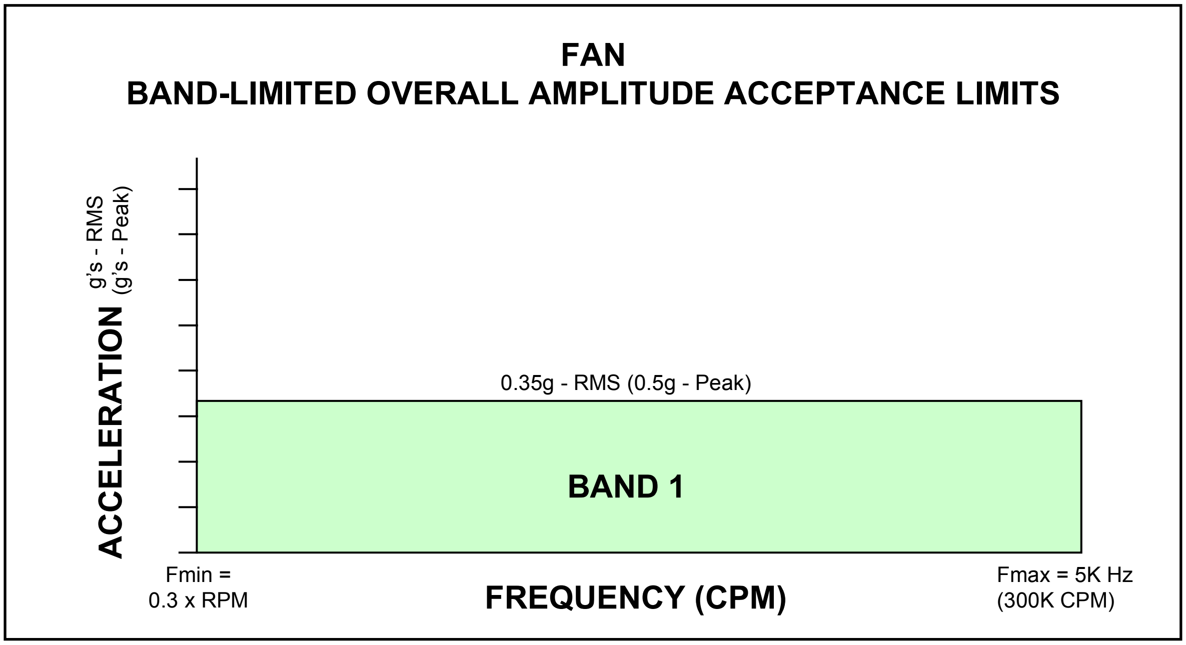

FIGURE 9.3.2 Band-Limited Overall Amplitude Acceptance Limits for Fans

9.3.6 OTHER REQUIREMENTS

9.3.6.1 Variable speed sheaves shall not be used in the final installation.

9.3.6.2 Drive sheave and driven sheave should differ in size by 20 % or more to avoid *beat* vibration.

9.3.7 FAN CERTIFICATION

9.3.7.1 The maximum Line Amplitude of vibration in each Band at all bearing positions in any direction (radial and axial) as required by Table 9.3 shall be listed in tabular form.

9.3.7.2 The maximum Band Limited Overall Amplitude of vibration at all bearing positions in any direction (radial and axial) as required by Table 9.3 shall be listed in tabular form.

9.3.7.3 Vibration signatures of velocity and acceleration for Radial vibration measurements taken at 0^o and 90^o, at each bearing Position and one (1) Axial Position shall be submitted as part of the fan certification. If at any bearing Position, due to machine mounting constraints, radial vibration readings at 0^o and 90^o are not accessible, then two accessible radial readings 90^o apart shall be taken at said Position.

9.3.7.4 Vibration data and signatures must be submitted with the fan to the purchaser's Maintenance Department or other authorized representative before acceptance of the fan/machine will be authorized.

TOC

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SECTION 9.4

GM VIBRATION STANDARDS

FOR PUMPS

9.4.1 Pumps shall be defined in two (2) categories:

- Positive Displacement including, but not limited to Piston, Gear, and Vane.
- Centrifugal

9.4.2 OPERATING CONDITIONS

9.4.2.1 Non-cavitating non-separating condition.

9.4.2.2 No piping strain.

9.4.2.3 Shaft coupling aligned (Reference: GM Alignment Standards and Section 7.8, p. 13, this specification).

9.4.2.4 Straight suction pipe to pump (Reference Hydraulic Institute Standard).

9.4.2.5 Certification shall be performed while pumps are operating within design specifications.

9.4.3 LIMITS FOR POSITIVE DISPLACEMENT & CENTRIFUGAL PUMPS

9.4.3.1 For purposes of Line Amplitude evaluations a *Pumping Frequency* (PF) band will be established. The PF Band will be centered on the Pumping Frequency (Number of pumping elements X Pump RPM). The band will extend ± 2 lines of resolution on either side of the line of resolution containing the Pumping Frequency (i.e. Bandwidth = 5 lines of resolution).

9.4.3.2 Excluding the lines of resolution contained in the Pumping Frequency (PF) Band, the velocity amplitude of any line of resolution, measured at all bearing locations in any direction radial or axial shall not exceed the Line-Amplitude Band Limit values specified in Table 9.4.A and graphed in Figure 9.4.1.

9.4.3.3 The Velocity Band-Limited Overall Amplitude at all bearing locations in any direction radial or axial shall not exceed the Pumping Frequency Band Limited Overall Amplitude Acceptance Limit value specified in Table 9.4 and graphed in Figure 9.4.1.

9.4.3.4 The Acceleration Band-Limited Overall Amplitude at all bearing locations in any direction radial or axial shall not exceed the Band-Limited Overall Amplitude Acceptance Limit values specified in Table 9.4 and graphed in Figure 9.4.2.

TOC

TABLE 9.4 MAXIMUM ALLOWABLE VIBRATION LEVELS FOR POSITIVE DISPLACEMENT AND CENTRIFUGAL PUMPS

LINE-AMPLITUDE BAND LIMITS			
BAND	FREQUENCY RANGE Hz (CPM)	VELOCITY MM/SEC RMS	(INCH/SEC - PEAK)
1	[0.3 → 0.8] x RPM	0.718	(0.04)
2	[0.8 → 1.2] x RPM	1.35	(0.075)
3	[1.2 → 3.5] x RPM	0.718	(0.04)
4	3.5 x RPM → 2,000 Hz (120,000 CPM)	0.54	(0.03)

BAND-LIMITED OVERALL AMPLITUDE LIMITS				
BAND	FREQUENCY RANGE Hz (CPM)		ACCELERATION g's RMS	(g's PEAK)
1	0.3 x RPM → 5K Hz (300K CPM)	POSITIVE DISPLACEMENT	1.06	(1.5)
		NON-POSITIVE DISPLACEMENT	0.707	(1.0)
PUMPING FREQ. BAND (PF)	FREQUENCY RANGE Hz (CPM)		VELOCITY MM/SEC RMS	(INCH/SEC - PEAK)
BAND 5	5 Lines of resolution centered on PF.	PISTON	1.35	(0.075)
		VANE	0.89	(0.05)

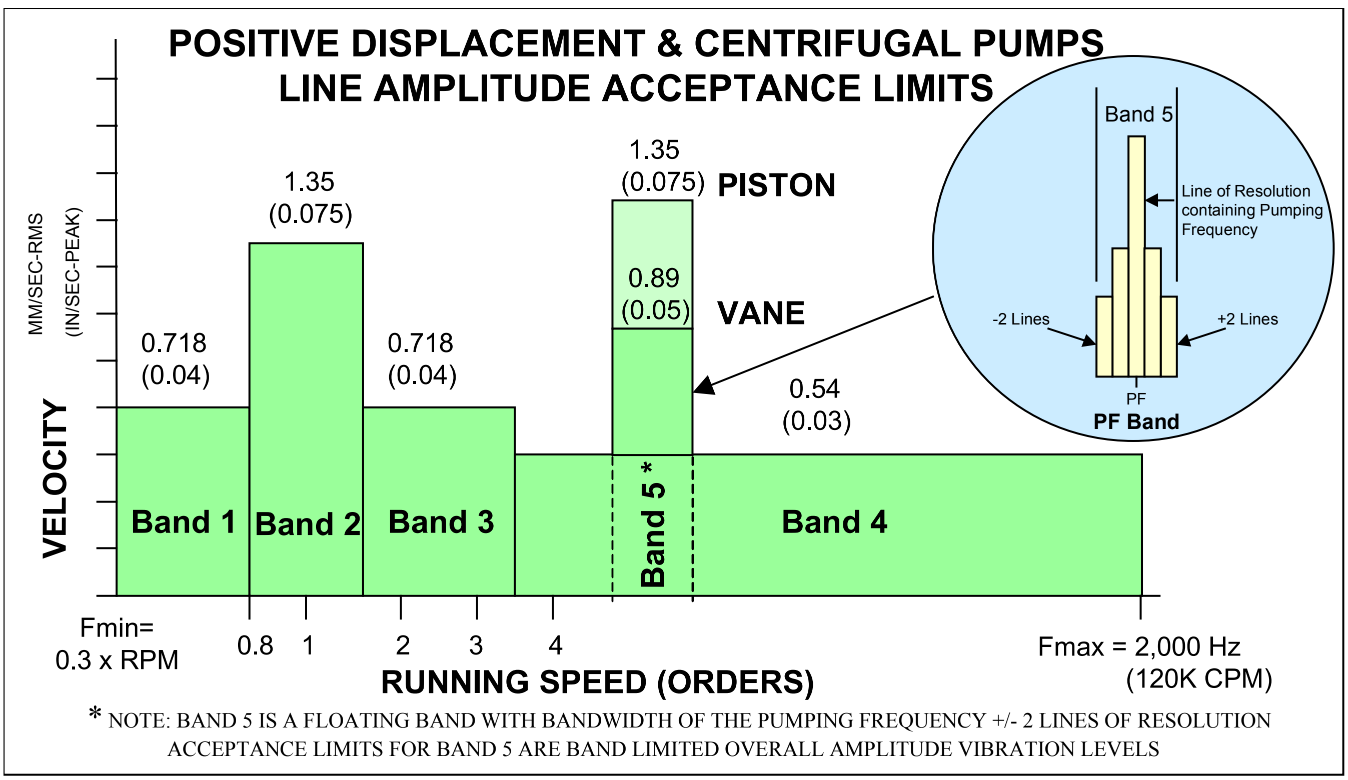

Figure 9.4.1 Line Amplitude Acceptance Limits for Positive Displacement & Centrifugal Pumps

TOC

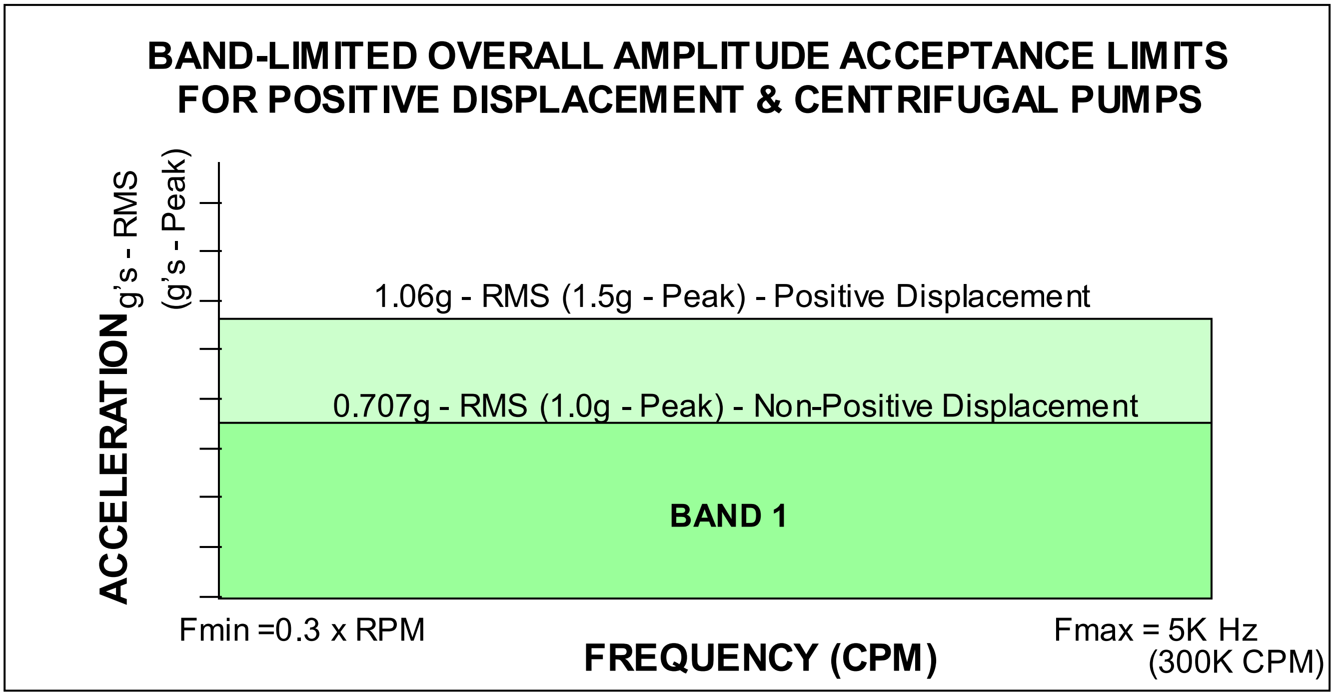

Figure 9.4.2 Band-Limited Overall Amplitude Acceptance Limits for Positive Displacement & Centrifugal Pumps

9.4.4 VERTICAL MOUNTED PUMPS

9.4.4.1 Vertically mounted pump systems with a *Vertical Mount Height* greater than 1.5 meters (5 feet) will have an allowable increase in Velocity Amplitude Acceptance Limits in Bands 1, 2, and 3 of 16.4% per meter (5% per foot) of *Vertical Mount Height* greater than 1.5 meters (5 feet). [E.g. A 2.134 meter (7 foot) Vertical Mount Height would yield a 10% increase [(2.134 meter - 1.5 meter) x 16.4%/meter], [(7 ft - 5 ft) x 5%/ft]) in the Table 9.4 Velocity Amplitude Acceptance Limits specified for Bands 1, 2, and 3). Therefore the limit for Band 1 would be 0.718 MM/SEC + [(0.718 MM/SEC) x (0.1)] = 0.79 MM/SEC - RMS,
(0.04 Inch/sec + [(0.04 Inch/sec) x (0.1)] = 0.044 Inch/sec-Peak).

9.4.4.2 Vertical Mount Height is defined as the furthest measurable distance from the machine mounting to the end of the driver or the end of the pump, which ever is greater.

9.4.5 PUMP CERTIFICATION

9.4.5.1 The maximum Line Amplitude of vibration in each Band at all bearing positions in any direction (radial and axial) as required by Table 9.4 shall be listed in tabular form.

9.4.5.2 The maximum Band Limited Overall Amplitude of vibration at all bearing positions in any direction (radial and axial) as required by Table 9.4 shall be listed in tabular form.

9.4.5.3 Vibration signatures of velocity and acceleration for Radial vibration measurements taken at 0^o and 90^o, at each bearing Position and one (1) Axial Position shall be submitted as part of the pump certification. If at any bearing Position, due to machine mounting constraints, radial vibration readings at 0^o and 90^o are not accessible, then two accessible radial readings 90^o apart shall be taken at said bearing Position.

9.4.5.4 Vibration data and signatures must be submitted with the pump to the purchaser's Maintenance Department or other authorized representative before acceptance of the pump/machine will be authorized.

TOC

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SECTION 9.5

GM VIBRATION STANDARDS

FOR GEARBOXES

9.5.1 VIBRATION LIMITS FOR GEARBOXES

Gearboxes up to a maximum of two (2) gear sets shall not exceed the vibration limits specified in Table 9.5.1 and graphically illustrated in Figures 9.5.1 and 9.5.2. For gearboxes with more than two (2) gear sets, acceptance limits will be established between purchaser and supplier.

TABLE 9.5.1 MAXIMUM ALLOWABLE VIBRATION LEVELS FOR GEARBOXES WITH ≤ TWO (2) GEAR SETS

VELOCITY LINE-AMPLITUDE BAND LIMITS

BAND	FREQUENCY RANGE Hz (CPM)	VELOCITY MM/SEC RMS	(INCH/SEC - PEAK)
1	[0.3 → 0.8] x RPM	0.718	(0.04)
2	[0.8 → 1.2] x RPM	1.35	(0.075)
3	[1.2 → 3.5] x RPM	0.718	(0.04)
4	[3.5 → 8.5] x RPM	0.54	(0.03)
5	8.5 x RPM → 1,000 Hz (60,000 CPM)	0.54	(0.03)
6	[1,000 → 2,000] Hz (60,000 → 120,000 CPM)	0.54	(0.03)

ACCELERATION BAND-LIMITED OVERALL AMPLITUDE LIMITS

BAND	FREQUENCY RANGE Hz (CPM)	g's RMS	(g's PEAK)
1	0.3 x RPM → 3.5 x GMF or 10K Hz (600K CPM) Which ever is Greater	0.707	(1.0)

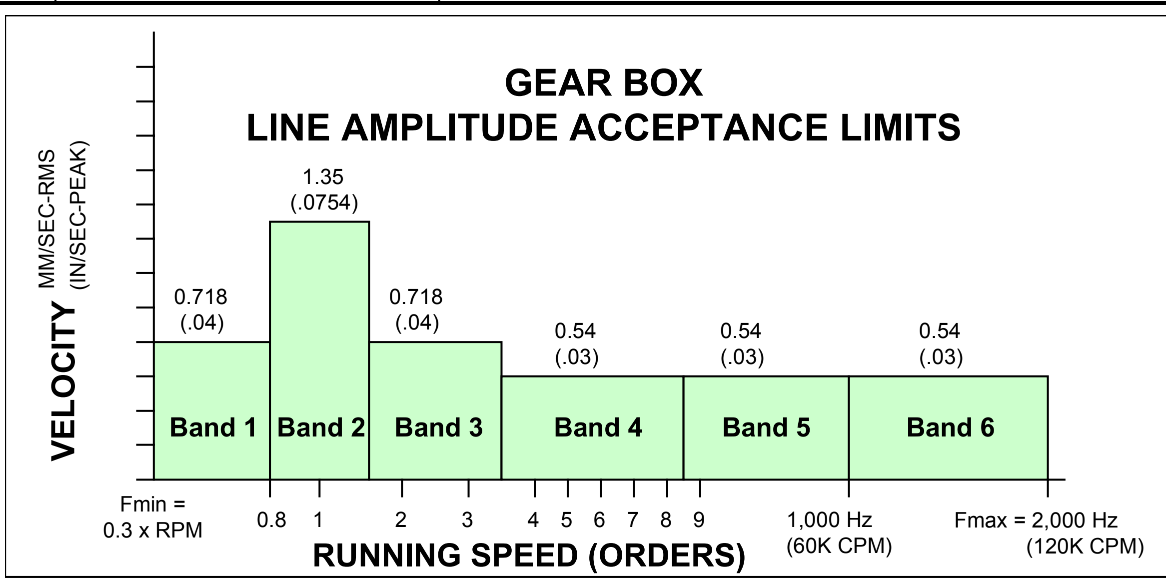

Figure 9.5.1 Line Amplitude Acceptance Limits for Gearboxes

TOC

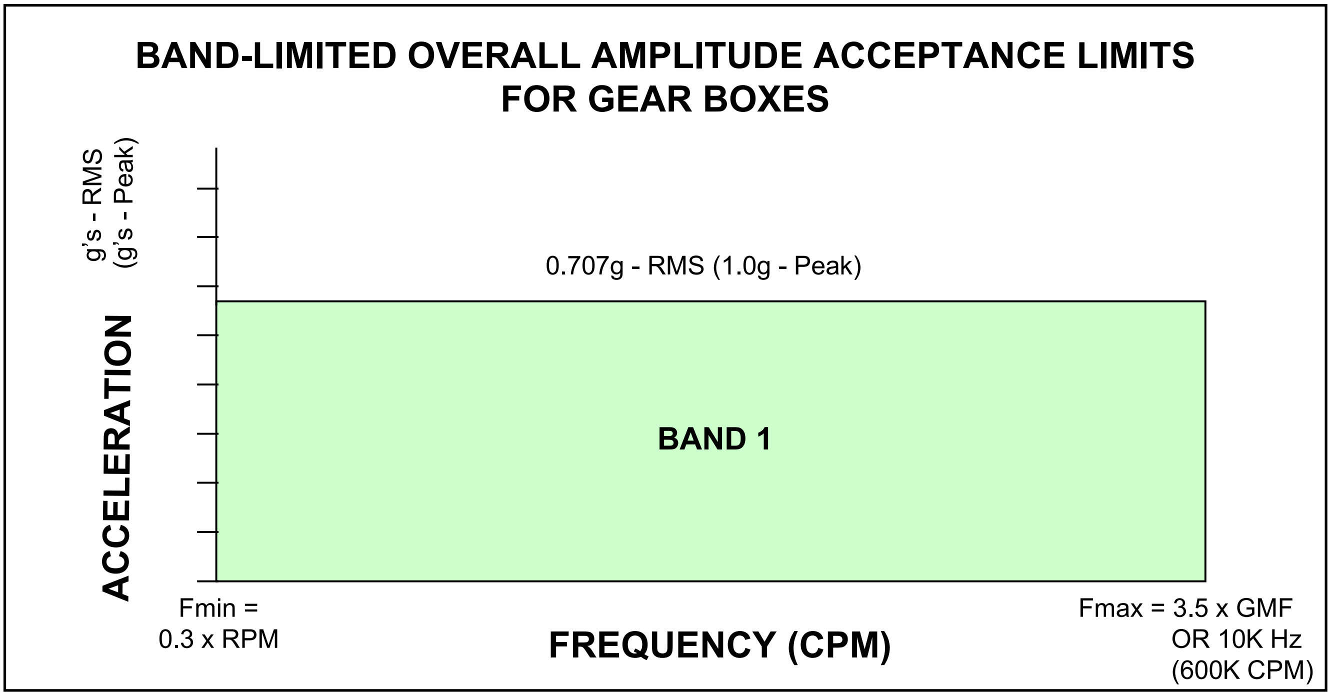

Figure 9.5.2 Band-Limited Overall Amplitude Acceptance Limits for Gearboxes

9.5.2 GEARBOX CERTIFICATION

9.5.2.1 The maximum Line Amplitude of vibration in each Band at all bearing positions in any direction (radial and axial) as required by Figure 9.5.1 shall be listed in tabular form.

9.5.2.2 The maximum Band Limited Overall Amplitude of vibration at all bearing positions in any direction (radial and axial) as required by Figure 9.5.2 shall be listed in tabular form.

9.5.2.3 Vibration signatures of velocity and acceleration for Radial vibration measurements taken at 0^o and 90^o, at each bearing Position and one (1) Axial Position shall be submitted as part of the gearbox certification. If at any bearing Position, due to machine mounting constraints, radial vibration readings at 0^o and 90^o are not accessible, then two accessible radial readings 90^o apart shall be taken at said Position.

9.5.2.4 Vibration data and signatures must be submitted with the gearbox to the purchaser's Maintenance Department or other authorized representative before acceptance of the gearbox/machine will be authorized.

TOC

SECTION 9.6

GM VIBRATION STANDARDS

FOR DEFAULT VIBRATION LEVEL LIMITS

If Vibration Limit values are not available for the machine being considered, the Specification Limit shall (unless specified otherwise by the purchaser) default to the following:

9.6.1 NON-MACHINE TOOLS and NON-PRECISION MACHINE TOOLS

Non-machine Tools and Non-precision Machine Tools shall not exceed the Vibration Limits specified in Table 9.6.1 and graphically illustrated in Figures 9.6.1 and 9.6.3.

TABLE 9.6.1 MAXIMUM ALLOWABLE VIBRATION LEVELS FOR NON-MACHINE TOOLS and NON-PRECISION MACHINE TOOLS			
VELOCITY LINE-AMPLITUDE BAND LIMITS			
BAND	FREQUENCY RANGE Hz (CPM)	VELOCITY MM/SEC RMS	(INCH/SEC - PEAK)
1	[0.3 → 0.8] x RPM	0.718	(0.04)
2	[0.8 → 1.2] x RPM	1.35	(0.075)
3	[1.2 → 3.5] x RPM	0.718	(0.04)
4	[3.5 → 8.5] x RPM	0.54	(0.03)
5	8.5 x RPM → 1,000 Hz (60,000 CPM)	0.54	(0.03)
6	[1,000 → 2,000] Hz (60,000 → 120,000 CPM)	0.54	(0.03)
ACCELERATION BAND-LIMITED OVERALL AMPLITUDE LIMITS			
BAND	FREQUENCY RANGE Hz (CPM)	g's RMS	(g's PEAK)
1	0.3 x RPM → 5K Hz (300K CPM)	0.35	(0.5)

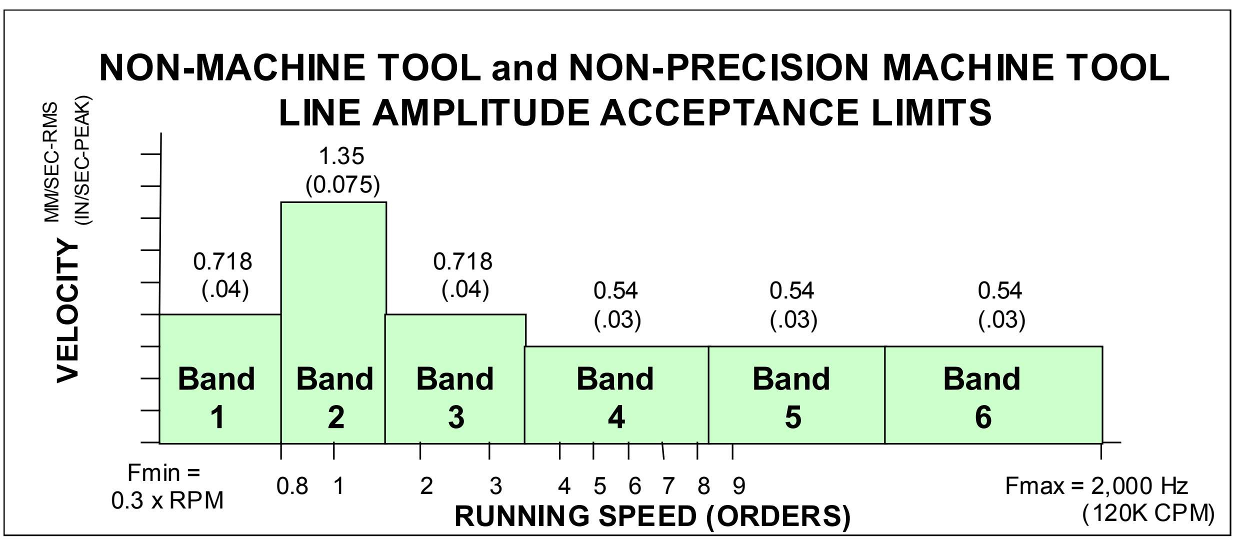

Figure 9.6.1 Line Amplitude Acceptance Limits for Non-Machine Tools and Non-Precision Machine Tools

TOC

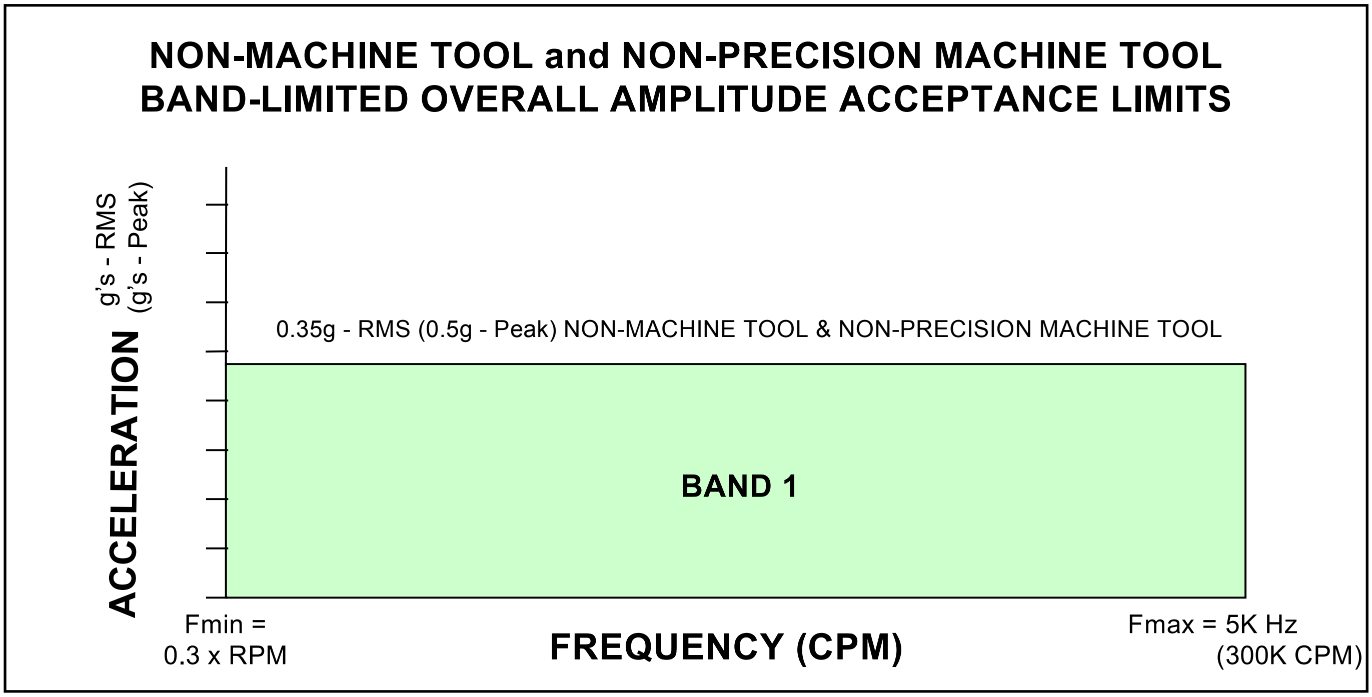

Figure 9.6.2 Band-Limited Overall Amplitude Acceptance Limits for Non-Machine Tools & Non-Precision Machine Tools

9.6.2 PRECISION MACHINE TOOLS

Precision Machine Tools shall not exceed the Vibration Limits specified in Table 9.6.2 and graphically illustrated in Figures 9.6.3 and 9.6.4.

TABLE 9.6.2 MAXIMUM ALLOWABLE VIBRATION LEVELS FOR PRECISION MACHINE TOOLS				
LINE-AMPLITUDE BAND LIMITS				
BAND	FREQUENCY RANGE Hz (CPM)		VELOCITY MM/SEC RMS	(INCH/SEC - PEAK)
1	[0.3 → 0.8] x RPM		0.36	(0.02)
2	[0.8 → 1.2] x RPM		0.36	(0.02)
3	[1.2 → 3.5] x RPM		0.18	(0.01)
4	3.5 x RPM → 2,000 Hz (120,000 CPM)	Angular Contact Bearings	0.09	(0.005)
		Roller Bearings	0.135	(0.0075)
BAND-LIMITED OVERALL AMPLITUDE LIMITS				
BAND	FREQUENCY RANGE Hz (CPM)		ACCELERATION g's RMS	(g's PEAK)
1	0.3 x RPM → 10K Hz (600K CPM)	Angular Contact Bearings	0.35	(0.5)
		Roller Bearings <= 1,000 RPM	0.707	(1.0)
		Roller Bearings > 1,000 RPM	1.06	(1.5)

TOC

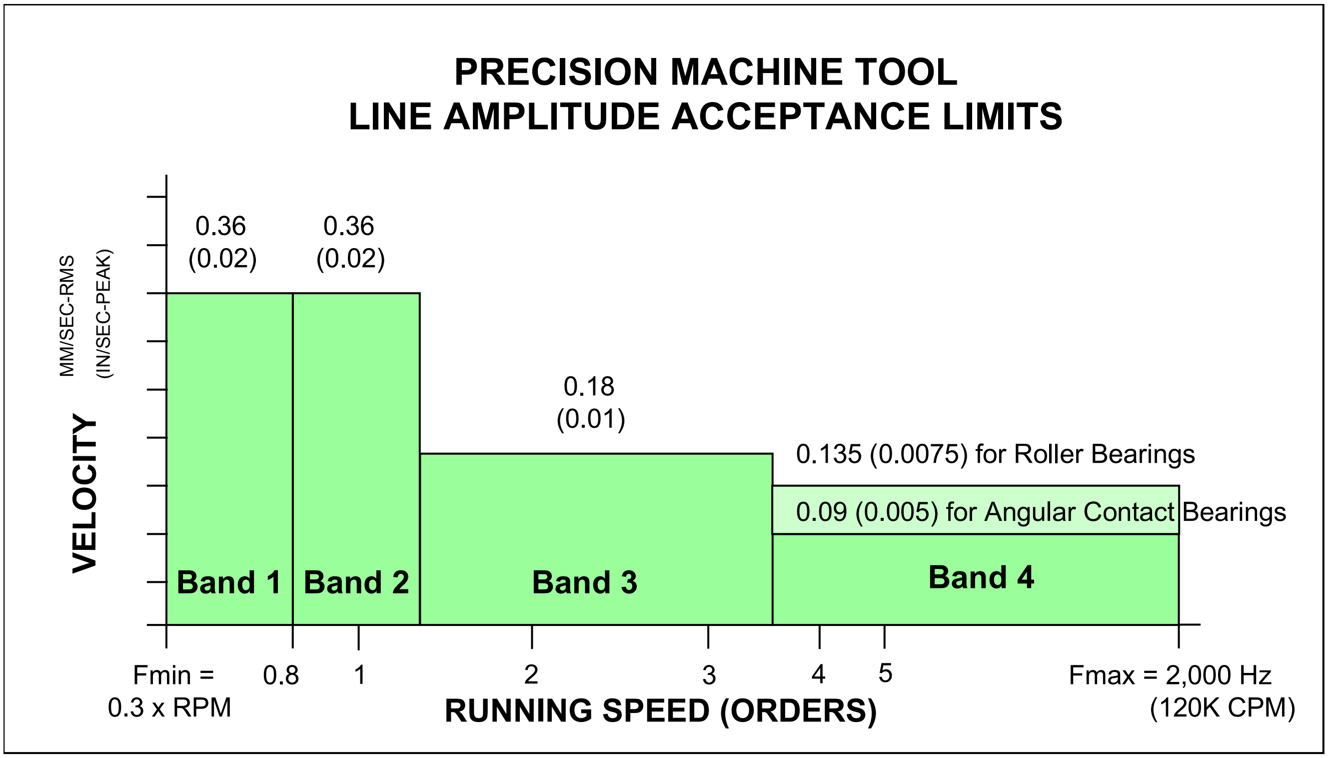

Figure 9.6.3 Line Amplitude Acceptance Limits for Precision Machine Tools

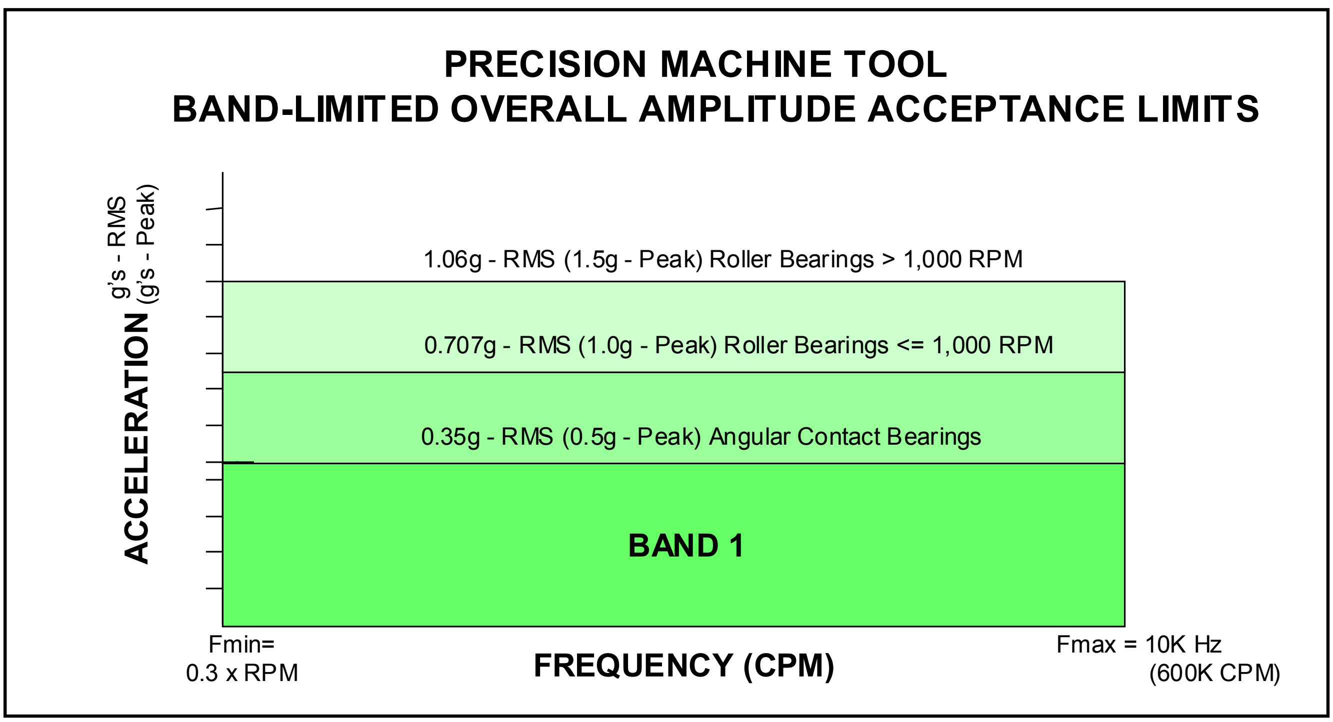

Figure 9.6.4 Band-Limited Overall Amplitude Acceptance Limits for Precision Machine Tools

TOC

9.6.3 DEFAULT CERTIFICATION

9.6.3.1 The maximum Line Amplitude of vibration in each Band at all bearing positions in any direction (radial and axial) as required by Table 9.6.1 or 9.6.2 shall be listed in tabular form.

9.6.3.2 The maximum Band Limited Overall Amplitude of vibration at all bearing positions in any direction (radial and axial) as required by Table 9.6.1 or 9.6.2 shall be listed in tabular form.

9.6.3.3 Vibration signatures of velocity and acceleration for Radial vibration measurements taken at 0^o and 90^o, at each bearing Position and one (1) Axial Position shall be submitted as part of the machine certification. If at any bearing Position, due to machine mounting constraints, radial vibration readings at 0^o and 90^o are not accessible, then two accessible radial readings 90^o apart shall be taken at said Position.

9.6.3.4 Vibration data and signatures must be submitted with the machine to the purchaser's Maintenance Department or other authorized representative before acceptance of the machine will be authorized.

TOC

APPENDIX A

RECOMMENDED COMPONENT IDENTIFICATION SYMBOLS

AGB	AUXILIARY GEARBOX
ANG	ANGLE
ARS	ARBOR SUPPORT
ASY	ASSEMBLY
BLR	BLOWER
BLT	BELT
BRG	BEARING
BRK	BRAKE
BSE	BASE
BSH	BUSHING
BTM	BOTTOM
CHN	CHAIN
CLP	CLAMP
CLS	CLUSTER
CLH	CLUTCH
CMP	COMPENSATOR
CMS	CAMSHAFT
CLT	COOLANT
CPG	COUPLING
CPR	COMPRESSOR
CRK	CRANKSHAFT
CTF	CENTRIFUGAL
CTR	CENTER
CUT	CUTTER
DBL	DOUBLE
DIE	DIE
DIS	DISTRIBUTOR
DPT	DEPARTMENT
DRV	DRIVE
DRB	DRAW BAR
DRL	DRILL
DRV	DRIVE
ENC	ENCODER
EXH	EXHAUST
FAN	FAN
FDD	FEED DRIVE
FRM	FRAME
FRT	FRONT
FWL	FLYWHEEL
FXT	FIXTURE
GBX	GEAR BOX
GEN	GENERATOR
GER	GEAR
GHD	GEARED HEAD
GIB	GIB
GRD	GUARD
GRW	GRIND WHEEL
HDS	HEADSTOCK
HED	HEAD
HSG	HOUSING
HYD	HYDRAULIC
IDL	IDLER
IDP	IDLER PULLEY
INB	IN BOARD
ITK	INTAKE
JKS	JACKSHAFT
KWY	KEYWAY
LTH	LATHE
MAG	MAGNETIC
MIL	MILLING MACHINE
MTR	MOTOR

MUL	MULTIPLE
OTB	OUTBOARD
PIN	PINION
PLB	PILLOW BLOCK
PLT	PLANT
PLY	PULLEY
PMP	PUMP
PRC	PRECISION
PSN	PISTON
QUL	QUILL
RER	REAR
RTR	ROTOR
RNR	RUNNER
SFT	SHAFT
SGL	SINGLE
SHV	SHEAVE
SLV	SLEEVE
SPK	SPROCKET
SPL	SPINDLE
SPN	SPLINE
STA	STATION
STD	STANDARD
STG	STAGE
SYS	SYSTEM
TBL	TABLE
TBO	TURBO
TDM	TANDEM
TLS	TAILSTOCK
TOL	TOOL
TOP	TOP
TRB	TURBINE
UNT	UNIT
VAC	VACUUM PUMP
VNE	VANE
WAY	WAY
WHL	WHEEL
WJK	WATER JACKET
WKH	WORK HEAD
WLH	WHEEL HEAD
WRC	WRENCH
WSR	WASHER

The machine tool builder and the purchaser should agree upon other Component Symbols not listed above on an as-needed basis.

TOC

APPENDIX B

GLOSSARY

ACCELERATION: The time rate of change of velocity. Typical units are ft/sec^2 and g's (1 g = 32.17 ft/sec^2 = 386 in/sec^2 = 9.81 meter/sec^2). Acceleration measurements are made with accelerometers.

> *Note: By international agreement, the value 9.80665 m/s^2 = 980,665 cm/s^2 = 386.089 in/s^2 = 32.174 ft/s^2 has been chosen as the standard acceleration due to gravity (g). ISO 2041 (1990)*

ACCELEROMETER: Transducer whose output is directly proportional to acceleration. Most commonly used are mass loaded piezoelectric crystals to produce an output proportional to acceleration.

AMPLITUDE: A measure of the severity of vibration. Amplitude is expressed in terms of peak-to-peak, zero-to-peak (peak), or rms. For pure sine waves only:

- Peak (P) = 1.414 x RMS
- Peak-to-Peak = 2 x Zero-to-Peak (Peak)

ANTI-ALIASING FILTER: A low-pass filter designed to filter out frequencies higher than 1/2 the sample rate in order to prevent aliasing.

ANTI-FRICTION BEARING: See ROLLING ELEMENT BEARING.

AVERAGE: The sum of the values of the measurements taken divided by the number of measurements taken.

BALANCE: When the mass centerline and rotational centerline of a rotor are coincident.

BALANCE QUALITY GRADE - GXXX: For rigid rotors, G, is the product of specific unbalance, e, and rotor maximum service angular velocity. Service angular velocity is service RPM expressed in radians per second.

$$G = e \times \omega = \text{constant}$$

BALANCING: A procedure for adjusting the radial mass distribution of a rotor by adding or removing weight, so that the mass centerline approaches the rotor geometric centerline achieving less vibration amplitude at rotational speed.

BAND-LIMITED OVERALL AMPLITUDE: For vibration level limits specified in terms of "BAND-LIMITED OVERALL AMPLITUDE LIMITS" the Total vibration level "A" in a band, as defined by the following equation, shall not exceed the Overall Amplitude Acceptance Limit specified for the Band.

$$A = \sqrt{\frac{\sum_{i=1}^{N} A_i^2}{W}}$$

A	=	Overall vibration level in the Band
A_i	=	Amplitude in the ith line of resolution in the Band
(i = 1)	=	The first line of resolution in the Band
(i = N)	=	The last line of resolution in the Band
N	=	The number of lines of resolution in the Band
W	=	Window Factor (W = 1.5 for a Hanning Window)

BEATS: Periodic variations in the amplitude of an oscillation resulting from the combination of two oscillations of slightly different frequencies. The beats occur at the difference frequency. ISO 2041 (1990).

BEAT FREQUENCY: The absolute value of the difference in frequency of two oscillations of slightly different frequencies ISO 2041 (1990).

BIN: A frequency bandwidth (Δf) determined by Fmax divided by the number of lines of resolution. While commonly referred to and represented by a line of resolution, a Bin contains a bandwidth of frequencies. (Refer to LINE OF RESOLUTION)

BLADE PASS FREQUENCY (PUMPING FREQUENCY): A potential vibration frequency on any bladed machine (turbine, axial compressor, fan, pump, etc.). It is represented by the number of fan blades or pump vane times shaft rotating frequency.

CALIBRATION: A test to verify the accuracy of measurement instruments. For vibration, a transducer is subjected to a known motion, usually on a shaker table, and the output readings are verified or adjusted.

COMPLETE MACHINE: A complete machine is defined as the entire assembly of components, sub-components, and structure, which is purchased to perform a specific task(s). On a Complete Machine Assembly with all individual components operating in their normal operating condition, mode, and sequence, the Component Vibration Level Limits for the complete machine acceptance are the same as when the component is tested individually.

CRITICAL SPEED: The speed of a rotating system corresponding to a system resonance frequency.

DECIBEL (dB): A logarithmic representation of amplitude ratio, defined as 20 times the base ten logarithm of the ratio of the measured amplitude to a reference. dBV readings, for example, are referenced to 1 volt rms. dB amplitude scales are required to display the full dynamic range of an FFT Analyzer.

DISPLACEMENT: The distance traveled by a vibrating object. For purposes of this document, displacement represents the total distance traveled by a vibrating part or surface from the maximum position of travel in one direction to the maximum position of travel in the opposite direction (Peak-to-Peak) and is measured in the unit mil (1 mil = 0.001 inch).

DYNAMIC RANGE: The difference between the highest measurable signal level and the lowest measurable signal level that is detectable for a given Amplitude Range setting. Dynamic Range is usually expressed in decibels, typically 60 to 90 dB for modern instruments.

DYNAMIC MASS: To determine if the mass of the transducer is effecting the measurement, perform the following steps:

a. Make the desired measurement with the accelerometer.
b. Place a mass equivalent to the mass of the accelerometer adjacent to the measuring accelerometer.
c. Repeat the measurement.
d. Compare data from a. and c.
e. If any differences (i.e. shift in frequencies) between a. and c. exist, then a less massive transducer should be used in a.

FFT (FAST FOURIER TRANSFORM): A calculation procedure which produces a mathematical relationship between the time domain and the frequency domain resulting in discrete frequency components from the sampled time data.

FFT ANALYZER: Vibration analyzer that uses the Fast Fourier Transform to display vibration frequency components.

FIELD BALANCING: The process of balancing a rotor in its own bearings and supporting structure rather than in a balancing machine.

FFT (FAST FOURIER TRANSFORM): A calculation procedure which produces a mathematical relationship between the time domain and the frequency domain resulting in discrete frequency components from the sampled time data.

FLEXIBLE ROTOR: A rotor that deforms significantly at running speed. This term is used for rotors that operate close to or above their first critical speed. A rotor is considered flexible when its speed is more than 75% of its lowest natural frequency in bending.

FORCED VIBRATION: The oscillation of a system under the action of a forcing function. Typically forced vibration occurs at the frequency of the exciting force.

FREE VIBRATION: Vibration of a mechanical system following an initial force typically at one or more natural frequencies.

FREQUENCY: The repetition rate of a periodic event, usually expressed in cycles per second (Hertz -abr. HZ), cycles per minute (CPM), or multiples of rotational speed (Orders). Orders are commonly referred to as 1X for rotational speed, 2X for twice-rotational speed, etc. Frequency is the reciprocal of the Period.

> NOTE: Vibration frequencies are expressed in Hertz (cycle per sec) or CPM (cycle per minute). Rotational speed (Running Speed) is expressed in RPM (Revolutions per minute).

FREQUENCY DOMAIN: Presentation of a signal whose amplitude is measured on the Y-axis, and the frequency is measured on the X-axis.

FREQUENCY RESOLUTION (Δf): $\Delta f = (F_{MAX} - F_{MIN})/\#$ Lines of resolution. Δf represents the minimum spacing between data points in the spectrum.

F_{MAX}: Maximum Frequency Limit of the spectrum being evaluated.

F_{MIN}: Minimum Frequency Limit of the spectrum being evaluated.

FREQUENCY RESPONSE: Portion of the frequency spectrum, which can be covered within specified frequency limits.

g: The value of acceleration produced by the force of gravity. (32.17 ft/sec^2, 386 in/sec^2, 9.81 m/sec^2).

GEAR MESH FREQUENCY: A potential vibration frequency on any machine that contains gears: equal to the number of teeth multiplied by the rotational frequency of the gear.

HANNING WINDOW: An FFT window function that provides better frequency resolution than the flat top window, but with reduced amplitude accuracy.

HARMONIC: Frequency component at a frequency that is an integer (whole number e.g. 2X, 3X, 4X, etc.) multiple of the fundamental (reference) frequency.

HI BANDPASS FILTER: A device that separates the components of a signal and allows only those components above a selected frequency to be amplified.

HERTZ (Hz): The unit of frequency represented by cycles per second.

INTEGRATION: A process producing a result that when differentiated, yields the original quantity. Integration of acceleration, for example, yields velocity. Integration is performed in an FFT Analyzer by dividing by $2\pi f$ where f is the frequency of vibration. Integration is also used to convert velocity to displacement.)

LARGE APPARATUS AC/DC MOTORS: Reference NEMA Publication No. MG 1, Motors and Generators, Section III LARGE MACHINES, Part 20. Induction Machines, Part 21. Synchronous Motors, and Part 23. DC Motors.

LINEAR NON-OVERLAPPING AVERAGE: An averaging process where each Time block sample used in the averaging process contains data not contained in other Time blocks (i.e. non-overlapping) used in the averaging. Linear averaging is performed in the Frequency Domain, and each sample is weighted equally.

LINES: The total number of data points in a spectrum (e.g. 400, 800, 1600, etc.). See also **BIN**

LINE AMPLITUDE LIMIT: The maximum amplitude of any line of resolution contained within a band shall not exceed the Line Amplitude Acceptance Limit for the Band.

LINE OF RESOLUTION: A single data point from a spectrum, which contains vibration amplitude information. The Line of Resolution amplitude is the Band Overall Amplitude of the frequencies contained in the Δf Frequency Resolution.

MEASUREMENT POINT: A location on a machine or component at which vibration measurements are made.

MICROMETER (MICRON): One-millionth (0.000001) of a meter. (1 micron = 1 x E-6 meters = 0.04 mils.)

MIL: One thousandth (0.001) of an inch. (1 mil = 25.4 microns.)

NATURAL FREQUENCY: The frequency of free vibration of a system when excited with an impact force. (Bump Test).

ORDER: A unit of frequency unique to rotating machinery where the first order is equal to rotational speed. See FREQUENCY

BAND LIMITED OVERALL READING: The vibration severity amplitude measured over a frequency range defined by an F_{MIN} and an F_{MAX}.

PEAK: Refers to the maximum of the units being measured, i.e., peak velocity, peak acceleration, and peak displacement.

PEAK-TO-PEAK: Refers to the displacement from one travel extreme to the other travel extreme. In English units, this is measured in mils (.001 inch) and in metric units it is expressed in micrometer µM (.000001 meters).

PERIOD: The amount of time, usually expressed in seconds or minutes, required to complete one cycle of motion of a vibrating machine or machine part. The reciprocal of the period is the frequency of vibration.

PHASE (PHASE ANGLE): The relative position, measured in degrees, of a vibrating part at any instant in time to a fixed point or another vibrating part. The Phase Angle (usually in degrees) is the angle between the instantaneous position of a vibrating part and the reference position. It represents the portion of the vibration cycle through which the part has moved relative to the reference position.

PRECISION SPINDLE: Spindles used in machining processes, which require high accuracy, high speed, or both.

RADIAL MEASUREMENT: Measurements taken perpendicular to the axis of rotation.

RADIAL VIBRATION: Shaft dynamic motion or casing vibration, which is in a direction perpendicular to the shaft centerline.

RESONANCE: The condition of vibration amplitude and phase change response caused by corresponding system sensitivity to a particular forcing frequency. A substantial amplitude increase and related phase shift typically identify a resonance.

RIGID ROTOR: A rotor that does not deform significantly at running speed. A rotor, whose parts do not take up motion relative to each other, i.e., all points move in the same direction at the same instant of time. A rotor is considered rigid when its speed is less than 75% of its lowest natural frequency in bending.

RMS: (Root mean square) Equal to 0.707 times the peak of a sinusoidal signal.

ROLLING ELEMENT BEARING: Bearing whose low friction qualities derive from rolling elements (balls or rollers), with little lubrication.

ROTATIONAL SPEED: The number of times an object completes one complete revolution per unit of time, e.g., 1800 RPM.

SIDE BAND: Equals the frequency of interest plus or minus one times the frequency of the exciting force.

SIGNATURE (SPECTRUM): Term usually applied to the vibration frequency spectrum which is distinctive and special to a machine or component, system or subsystem at a specific point in time, under specific machine operating conditions, etc. Usually presented as a plot of vibration amplitude (displacement, velocity or acceleration) versus time or versus frequency. When the amplitude is plotted against time it is usually referred to as the TIME WAVEFORM.

SOFTFOOT: A condition that exists when the bottoms of all of the feet of a machine are not in the same plane (can be compared to a chair with one short leg). Softfoot is present if the machine frame distorts when a foot bolt is loosened or tightened. It must be corrected before the machine is actually aligned.

TIME DOMAIN: Presentation of a signal whose amplitude is measured on the Y-axis and the time period is measured on the X-axis.

TRANSDUCER (PICKUP) - VIBRATION: A device that converts shock or vibratory motion into an electrical signal that is proportional to a parameter of the vibration measured. Transducer selection is related to the frequencies of vibration, which are important to the analysis of the specific machine(s) being evaluated/analyzed.

TRUE PEAK: The actual maximum amplitude of a complex waveform. Must be measured in the Time Domain. Peaks measured in the Frequency Domain represent the amplitudes of the Fourier Series sinewave components that have resulted from the Fourier Transform of the Time Waveform. These sinewave components when added together, by both amplitude and phase, will result in the true Time Waveform

UNBALANCE: Unequal radial weight distribution of a rotor system; a shaft condition such that the mass and shaft geometric centerlines do not coincide. There are three principle types of unbalance:

1. Static Unbalance - that condition of unbalance for which the central principle axis is displaced only parallel to the shaft axis.
2. Couple Unbalance - which condition of unbalance for which the central principal axis intersects the shaft axis at the center of gravity.
3. Dynamic Unbalance - that condition of unbalance for which the central principle axis is not parallel to and does not intersect the shaft axis. (Dynamic Unbalance is a combination of static and couple unbalance. This is the type of unbalance usually found.)

VELOCITY: The time rate of change of displacement with respect to some reference position. For purposes of this document, velocity is measured in the units Inch per second-Peak.

NOTE: THE REFERENCE FOR MANY OF THE DEFINITIONS IN THIS GLOSSARY IS THE GLOSSARY FROM THE HEWLETT PACKARD PUBLICATION "EFFECTIVE MACHINERY MEASUREMENTS USING DYNAMIC SIGNAL ANALYZERS," APPLICATION NOTE 243-1

TOC

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APPENDIX C

Page ____________ of___________

GENERAL MOTORS / DELPHI
VENDORS - VIBRATION DATA FORM AND CERTIFICATION SHEET

This form must accompany the machine certification vibration data. Vibration data must be presented in the GM Standard DataBase structure. (Reference Sections 4.0 and 5.0 of GM Specification V1.0-1999)

Issued By: Division:________________________________Plant:____
Address:____
____

A. MACHINE SPECIFICATIONS

Builder:____

Machine/Equipment
Identification Name:____

GM Purchase Order No.____GM Capital Tag No.__________________________

TYPE:____MODEL:______________________________

SERIAL NO.____CAPACITY:___________________________

SPEED:___________________________HORSEPOWER:_________________AUXILIARIES:_______________________

B. INSTRUMENTATION USED FOR CERTIFICATION

Instrument	Model	Serial No.	Certified Calibration Date
Vibration Meter			
Vibration Transducer			
Vibration Analyzer			
Vibration Software			

Other:

C. CERTIFICATION

Date:___________________________ Signed:____

Title:__________________________________ Company:____

D. ACCEPTANCE

____ _________________
Purchaser Authorized Representative Date

GENERAL MOTORS / DELPHI
VENDORS - VIBRATION DATA FORM AND CERTIFICATION SHEET

MACHINE INFORMATION DATA SHEET

MACHINE NAME________________________________ MACHINE ID CODE:_______________________________

DRIVER INFORMATION

DRIVER TYPE:__________________ BRAND:_______________ RPM:________________ HP:________

MANUFACTURER ID#:__________________________ CONSTANT SPEED?______ FRAME #:________________

BEARINGS: OUTBOARD: Manufacturer_____________________________Bearing ID#__________________________________

INBOARD: Manufacturer_______________________________Bearing ID#_________________________________

SLEEVE OR ROLLING ELEMENT? (CIRCLE ONE) SLEEVE ROLLING ELEMENT

IF DIRECT COUPLED, TYPE OF COUPLING:____

IF BELT DRIVEN, # OF BELTS:___________ BELT TYPE:________________________ # OF SHEAVES:_____________

LIST ALL SHEAVES WITH CORRESPONDING PITCH DIAMETER:____

____

BELT LENGTH:________________________ OR CENTER-TO-CENTER DISTANCE OF SHEAVES:____________________

GEARBOX?___________ IF YES, MANUFACTURER:______________________________________ I/O RATIO:_________

SHAFT	# OF TEETH	BEARING ID#
1ST INTERMEDIATE		
2ND INTERMEDIATE		
3RD INTERMEDIATE		
OUTPUT		

DRIVEN INFORMATION

DRIVEN TYPE (FAN, PUMP, GENERATOR, SPINDLE, ETC.)____

MANUFACTURER:______________________________ MANUF.ID#:_______________________ RPM:_______________

IF FAN OR PUMP. # OF VANES / PISTONS / BLADES / OTHER (←CIRCLE ONE):___________________________

BEARINGS: OUTBOARD: Manufacturer_____________________________Bearing ID#__________________________________

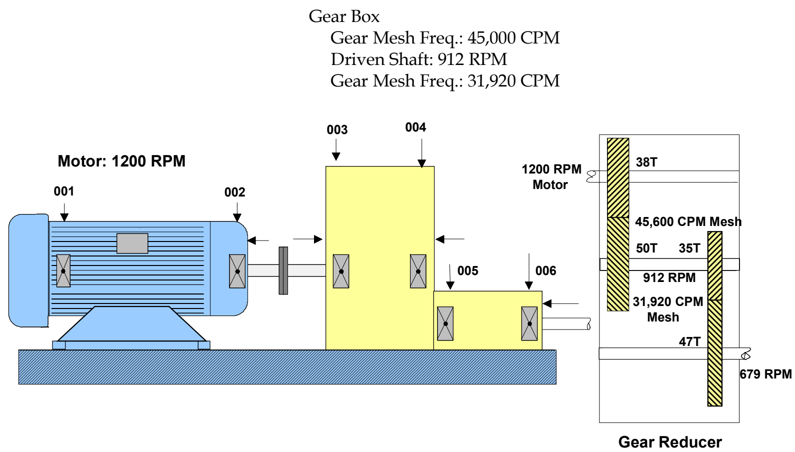
INBOARD: Manufacturer_______________________________Bearing ID#_________________________________

SLEEVE OR ROLLING ELEMENT? (CIRCLE ONE) SLEEVE ROLLING ELEMENT

COMMENTS:

GENERAL MOTORS / DELPHI
VENDORS - VIBRATION DATA FORM AND CERTIFICATION SHEET

Machine Layout Drawing Indicating Vibration Measurement Locations per Section 5.7



Motor - Gear Box Spindle System

EXAMPLE

GENERAL MOTORS / DELPHI
VENDORS - VIBRATION DATA FORM AND CERTIFICATION SHEET

Machine Layout Drawing Indicating Vibration Measurement Locations per Section 5.7 Contd.

TOC