National Electrical Manufacturers Association

Motor & Generator Balancing Specifications

ANSI/NEMA MG 1-2021 — Part 7: Vibration | Balance, Tolerances & Limits

1. Overview & Scope

ANSI/NEMA MG 1 (Motors and Generators) is the primary North American standard for electric motor and generator specifications. Part 7 of MG 1 specifically governs mechanical vibration — measurement conditions, evaluation criteria, and acceptance limits — for both AC and DC machines. Balancing requirements are embedded within the vibration acceptance framework, with NEMA linking rotor balance quality directly to in-service vibration velocity limits measured at bearing housings.

The standard covers DC machines tested with DC power and polyphase AC machines with sinusoidal power, in frame sizes 42 and larger, up to 100,000 HP / 75 MW, at speeds up to 3,600 RPM.

IMPORTANT NEMA MG 1 Part 7 specifies vibration limits for machines tested at no load and uncoupled from any driven load. These are factory acceptance limits only — they do not apply to in-situ installed machines. For installed machines, refer to ISO 10816-3.

2. NEMA Balance Approach — Vibration-Based Acceptance

Unlike ISO 21940-11 and API 610, which specify residual unbalance tolerances in g·mm or oz·in directly, NEMA MG 1 takes a vibration-velocity-based approach. The rotor is balanced to a level that achieves the prescribed bearing housing vibration velocity during the factory no-load test. The implicit rotor balance quality is ISO Grade G2.5 or better for standard motors.

NOTE NEMA MG 1 does not publish a separate residual unbalance formula (no equivalent of 4W/N or G × 9549/N). Instead, balance quality is verified by measuring bearing housing vibration velocity in in/sec (peak) or shaft vibration displacement in mils (peak-to-peak).

3. Bearing Housing Vibration Limits (MG 1 Part 7, Table 7-1)

The primary acceptance criterion is peak bearing housing vibration velocity measured at prescribed points in three directions (horizontal, vertical, axial). The limits below apply for machines tested at rated speed, no load, and uncoupled:

Mount Type	Speed Range	Max Velocity (in/sec peak)	Max Displacement (mils pk-pk)	Max Accel. (g peak)
Rigid Mount (massive foundation or test floor stand)	All speeds ≤ 3,600 RPM	0.12	2.0	0.8
Resilient Mount (free suspension)	All speeds ≤ 3,600 RPM	0.15	2.5	1.0

NOTE The standard uses peak (0-to-peak) values for velocity and acceleration, and peak-to-peak for displacement. This differs from ISO, which uses RMS for velocity and acceleration. To convert: peak = RMS × √2 ≈ RMS × 1.414.

4. Twice-Line-Frequency (2LF) Vibration — Two-Pole Machines

Two-pole induction machines (3,600 RPM on 60 Hz) may exhibit vibration at twice the line frequency (120 Hz). NEMA MG 1 provides a special allowance when the unfiltered housing vibration limit is exceeded but the excess is attributable solely to the 2LF component:

MG 1 Part 7 | 2LF Vibration Acceptance (Two-Pole Machines)

$$V_{1x} \le 0.12 \text{ in/sec} \quad \text{AND} \quad V_{2LF} \le 0.08 \text{ in/sec}$$

V_{1x} = Filtered vibration at 1× running speed (in/sec peak) — must not exceed 0.12 in/sec
V_{2LF} = Filtered vibration at twice line frequency (in/sec peak) — must not exceed 0.08 in/sec
2LF = Twice the line frequency = 2 × 60 Hz = 120 Hz (for 60 Hz supply)

IEEE Std 841 additionally specifies that filtered vibration at 2× speed (2n) or 2× frequency (2f) shall not exceed 0.05 in/sec, and unfiltered axial vibration shall not exceed 0.06 in/sec peak.

5. Elastic (Resilient) Mount Suspension Requirement

When machines are tested on resilient mounts (free suspension), the natural frequency of the suspension system must be sufficiently low to avoid interference with measurement. The minimum static displacement of the suspension is given by:

MG 1 Part 7 | Minimum Elastic Displacement for Resilient Mounting

$$Z = (a^2 \times g) / (2\pi \times n/60)^2 \times 1000$$

Z = Minimum static deflection of suspension (mm)

a = Frequency ratio $f_1/f_{no} \geq 3$ (lowest natural frequency of suspension must be ≤ 1/3 of machine speed frequency)
g = Gravitational acceleration = 9.82 m/s²
n = Nominal machine speed (RPM)

NOTE For machines below 600 RPM, resilient mounting is not practical. For machines above 3,600 RPM, use the static displacement value calculated at 3,600 RPM as the minimum.

6. Relative Shaft Vibration Limits

For machines fitted with sleeve (journal) bearings operating at or above 1,000 RPM, shaft vibration relative to the bearing housing may be measured in addition to — or instead of — housing vibration. Measurement requires prior agreement on probe installation between manufacturer and purchaser.

Measurement	Criterion	Limit	Units
Relative shaft vibration	Peak-to-peak displacement	2.0 mils (rigid mount)	mils pk-pk
Relative shaft vibration	Peak-to-peak displacement	2.5 mils (resilient mount)	mils pk-pk
Bearing housing velocity	Peak velocity (unfiltered)	0.12 in/sec (rigid mount)	in/sec peak
Bearing housing velocity	Peak velocity (unfiltered)	0.15 in/sec (resilient mount)	in/sec peak
Bearing housing accel.	Peak acceleration (unfiltered)	0.8 g (rigid mount)	g peak
Bearing housing accel.	Peak acceleration (unfiltered)	1.0 g (resilient mount)	g peak

7. Equivalent ISO Balance Grade and Residual Unbalance

Although NEMA MG 1 does not directly specify a residual unbalance tolerance in oz·in or g·mm, the implied balance quality for standard general-purpose motors corresponds to ISO Grade G2.5. The equivalent unbalance formulas from ISO 21940-11 may therefore be applied when a numeric unbalance tolerance is required:

NEMA Equivalent | Residual Unbalance in oz·in (ISO G2.5 basis)

$$U_{res} = 6.015 \times G \times W / N$$

U_res = Permissible residual unbalance (oz·in per correction plane)
G = Balance quality grade (mm/s) — use G = 2.5 for standard motors

W = Rotor weight (lb)
N = Maximum operating speed (RPM)
6.015 = Conversion constant derived from ISO G formula

NEMA Equivalent | Residual Unbalance in g·mm (ISO G2.5 basis)

$$U\_res = 9549 \times G \times m / N$$

U_res = Permissible residual unbalance (g·mm total)
G = Balance quality grade (mm/s) — G2.5 for standard; G1.0 for precision
m = Rotor mass (kg)
N = Maximum operating speed (RPM)

Per-Plane Unbalance | Symmetric Two-Plane Rotor

$$U\_plane = U\_res / 2$$

U_plane = Permissible residual unbalance per correction plane
U_res = Total permissible residual unbalance from formula above

NOTE For motor armatures repaired to the EASA standard (Section 2.7), dynamic balancing to ISO G2.5 is the default in the absence of a customer specification. G1.0 is the most common precision upgrade specification.

8. Shaft Key Convention (MG 1 Part 7.7.1)

For machines provided with a shaft extension keyway, the balancing and vibration measurement conditions are precisely defined to ensure repeatability:

Condition	Requirement
Keyway present on shaft	Insert a half-key during balancing and vibration measurement
Half-key definition	A key of full shaft length but half the normal depth — fills the keyway to the shaft OD level
Key design reference	ISO 21940-32 (Shaft and fitment key convention)
Purpose	Ensures that the unbalance contribution of the keyway is evenly distributed between shaft and fitment balancing

NOTE Failure to use a half-key during balancing — when the mating fitment (coupling hub, impeller) has a full key — will result in a systematic unbalance error at assembly. ISO 21940-32 defines three key conventions; NEMA MG 1 mandates the half-key convention.

9. Test Conditions Summary

Parameter	Requirement
Load condition	No load — machine uncoupled from any driven equipment
AC power supply	Rated frequency and rated voltage; sinusoidal waveform; voltage deviation factor ≤ 10%
Frequency tolerance	Within ±0.5% of rated test frequency
Voltage unbalance	≤ 1% (100 × max deviation from average / average voltage)
DC power supply	Armature voltage and field current matching the test speed; low-ripple power supply Type A
Multi-speed machines	Test at all operational speeds; limits must not be exceeded at any speed
Inverter-fed machines	Acceptable to test at speed corresponding to 60 Hz power supply only
Active environment check	If stationary vibration exceeds 25% of running vibration → active environment; criteria not given in Part 7
Measurement equipment accuracy	±10% of allowable limit; flat response 10 Hz to 1,000 Hz (ISO 2954)
Sensor type	Single-directional only; multi-directional sensors prohibited

10. Unit Conversions — NEMA vs. ISO

NEMA MG 1 uses inch-based units (in/sec, mils, g) as peak values, while ISO standards typically use metric units (mm/s) as RMS values. The following conversions apply:

Velocity | in/sec (peak) to mm/s (RMS)

$$V_{rms}\ [mm/s] = V_{peak}\ [in/sec] \times 25.4 / \sqrt{2} \approx V_{peak} \times 17.96$$

V_{peak} = Peak velocity (in/sec) — NEMA unit
V_{rms} = RMS velocity (mm/s) — ISO unit
$\times 25.4$ = Converts inches to millimetres
$/ \sqrt{2}$ = Converts peak to RMS (valid for sinusoidal signals)

Displacement | mils (pk-pk) to µm (pk-pk)

$$d\ [\mu m\ pk\text{-}pk] = d\ [mils\ pk\text{-}pk] \times 25.4$$

mils = Thousandths of an inch (0.001 in)
µm = Micrometres = millimetres × 1000

Unbalance | oz·in to g·mm

1 oz·in = 720 g·mm

oz·in = Ounce-inch (NEMA / API imperial unit)
g·mm = Gram-millimetre (ISO SI unit)

NEMA Limit	Value (peak)	ISO Equivalent (RMS)	Value (RMS)
Bearing velocity — rigid mount	0.12 in/sec pk	mm/s RMS	2.16 mm/s
Bearing velocity — resilient mount	0.15 in/sec pk	mm/s RMS	2.70 mm/s
Shaft displacement — rigid mount	2.0 mils pk-pk	µm pk-pk	50.8 µm
Shaft displacement — resilient mount	2.5 mils pk-pk	µm pk-pk	63.5 µm

11. Implied Balance Grade Comparison — NEMA, ISO & API

Standard	Balance Quality Grade	Typical Application	Tolerance Basis
NEMA MG 1 Part 7	ISO G2.5 (implied)	Standard general-purpose AC / DC motors	Vibration velocity limit: 0.12 in/sec (rigid)
NEMA MG 1 / EASA Precision Option	ISO G1.0	Precision motors; repaired armatures per EASA Std	Vibration velocity + explicit unbalance tolerance
ISO 21940-11	G2.5	Electric motors, pumps, fans, general machinery	U_per = 9549 × G × m / N (g·mm)
ISO 21940-11	G1.0	High-speed / precision motors and drives	U_per = 9549 × G × m / N (g·mm)
API 610 (assembled rotor)	~ISO G0.7	Centrifugal pump rotors	4W/N (oz·in) ≈ ISO G0.7
API 610 (impellers)	ISO G2.5	Individual impellers before assembly	U_per = 7 g·mm minimum

12. Worked Example — NEMA G2.5 to oz·in

Example: A 100 lb general-purpose AC motor rotor, 1,800 RPM, balanced to the NEMA MG 1 implied standard of ISO G2.5.

Step	Formula / Source	Result
1. Select G-Grade	NEMA MG 1 Part 7 implied standard	G = 2.5
2. Unbalance (oz·in total)	U = 6.015 × 2.5 × 100 / 1800	0.835 oz·in
3. Per plane (symmetric)	0.835 / 2	0.418 oz·in per plane
4. Correction mass @ 6 in radius	m = 0.418 / 6	0.070 oz max per plane
5. Vibration check (rigid mount)	Factory test ≤ 0.12 in/sec peak	Accept if ≤ 0.12 in/sec

13. Related Standards and Cross-References

Standard	Relationship to NEMA MG 1
ANSI/NEMA MG 1-2021	Master standard — motors and generators; Part 7 covers vibration
ANSI/NEMA MG 1, Part 31	Definite purpose inverter-fed motors; vibration test at 60 Hz equivalent speed only
ISO 21940-11 (replaces ISO 1940-1)	G-grade system referenced for balance quality; NEMA cites for residual unbalance tolerance method
ISO 21940-32	Shaft and fitment key convention — mandated by MG 1 Part 7.7.1 for keyway balancing
ISO 10816-3	Vibration of in-situ installed machines — referenced by MG 1 for field (not factory) evaluation
ISO 20816-1	Shaft vibration measurement criterion — referenced by MG 1 Part 7.4.2
ISO 10817-1	Shaft vibration measurement equipment requirements
ISO 2954	Vibration measurement instrument requirements (10 Hz – 1,000 Hz flat response)
IEC 60034-14	Vibration limits for rotating electrical machines — basis of NEMA MG 1 Part 7 elastic mount Figure 7-1
IEEE Std 841	Premium efficiency motors; stricter 0.08 in/sec limit at 2× speed / 2× frequency
EASA Standards	Repair of electrical apparatus; Section 2.7 specifies G2.5 default balancing on repair

IMPORTANT NEMA MG 1 vibration limits are no-load factory acceptance criteria only. Installed machines operating under load will typically exhibit higher vibration. For in-service monitoring and alarm setpoints, always reference ISO 10816-3 or site-specific acceptance criteria agreed between the purchaser and manufacturer.