Balance Quality Grade: Permissible Residual Unbalance, ISO 21940-11

balance_quality_grade_a ver 1.0 by Tom Irvine

Notation

G balance quality grade (mm/s), n maximum service speed (rpm), Ω angular speed (rad/s), m rotor mass, e_{per} permissible specific unbalance, U_{per} permissible residual unbalance, r correction radius, L_A, L_B distances from the rotor center of gravity to planes A and B, $L = L_A + L_B$.

Equations

1. Angular speed $\Omega = \dfrac{2\pi n}{60}$
2. Definition of the grade $e_{per}\,\Omega = G$ (G in mm/s)
3. Specific unbalance $e_{per} = \dfrac{1000\,G}{\Omega} = \dfrac{60000}{2\pi}\,\dfrac{G}{n} = 9549\,\dfrac{G}{n}$ [μm = g · mm/kg]
4. Residual unbalance $U_{per} = e_{per}\,m$ [g · mm, m in kg]
5. Correction mass at radius r $m_c = \dfrac{U_{per}}{r}$
6. Force at speed $F = U_{per}\,\Omega^2$ (U_{per} in kg · m → F in N)
7. Two planes, CG between them $U_{per,A} = U_{per}\,\dfrac{L_B}{L}, \qquad U_{per,B} = U_{per}\,\dfrac{L_A}{L}$
8. Limits on each share $0.3\,U_{per} \le U_{per,A},\ U_{per,B} \le 0.7\,U_{per}$

Grades: G 0.4, 1, 2.5, 6.3, 16, 40, 100, 250, 630, 1600, 4000 (steps of about 2.5). A custom value may be entered. If L_B/L is outside 0.3 to 0.7 the shares are limited to 30 % / 70 %. Outboard, overhung and narrow rotors use other allocation rules in the standard and are not covered.

Units

metric: m kg, r, L_A, L_B mm, e_{per} g·mm/kg = μm, U_{per} g·mm, m_c g, F N.

English: m lbm, r, L_A, L_B in, U_{per} oz·in, m_c oz, e_{per} in mil or oz·in/lb, F lbf.

U_{per} [oz · in] = $6.015\,G\,W/n$, W in lbm. 1 oz·in = 720.08 g·mm, 1 mil = 25.4 μm.

$F = U_{per}\,\Omega^2/386.088$ lbf, with U_{per} in lbm·in (oz·in / 16).

Assumptions

- Rigid rotor: no significant flexural deformation up to the maximum service speed.
- The grade is applied at the maximum service speed. U_{per} is the total for the rotor, referred to its center of gravity.
- The table of typical machine types for each grade is condensed from public summaries of the standard's Table 1.

Worked examples (checked in the test script)

1000 lbm rotor, 1800 rpm, G 6.3: $e_{per} = 33.42$ μm, $U_{per} = 15160$ g·mm = 21.05 oz·in (6.015 G W/n = 21.05).

Same rotor at 900 rpm, two symmetric planes: 21.05 oz·in per plane (IRD paper, Table 2: 21 oz-in).

Pump impeller 12 kg, 2950 rpm, G 6.3: $e_{per} = 20.39$ μm, $U_{per} = 244.7$ g·mm, 122.4 g·mm per plane (public example: 20.4 μm, 245 g·mm, 122 g·mm).

References

1. ISO 21940-11:2016, *Mechanical vibration – Rotor balancing – Part 11: Procedures and tolerances for rotors with rigid behaviour* (replaced ISO 1940-1:2003). Not consulted directly.
2. IRD Balancing, *Technical Paper 1: Balance Quality Requirements of Rigid Rotors* (summary of ISO 1940-1, incl. the 6.015 / 9549 constants, the h/b two-plane split and its 30–70 % limits).
3. Vibromera, *Balance Quality Grades: G0.4–G4000 Chart (ISO 1940-1)*, vibromera.eu (grade table, pump example).

Note: $e_{per}\Omega = G$ and $U_{per} = e_{per}m$ were confirmed in public sources. The plane allocation and the machine-type table are from public summaries of the standard: **check against ISO 21940-11**.