Amplification Factor & Separation Margin: Rotor Critical-Speed Acceptance

api_separation_margin_a ver 1.0 by Tom Irvine API Std 617 / API RP 684

Half-power (amplification factor) method

1. Critical speed — N_{c1} = speed of the peak amplitude A_{peak} (highest table point, parabolic refinement)

2. Half-power speeds — $A(N_1) = A(N_2) = 0.707\,A_{peak} = A_{peak}/\sqrt{2}, \qquad N_1 < N_{c1} < N_2$ (linear interpolation)

3. Amplification factor — $$AF = \frac{N_{c1}}{N_2 - N_1}$$

4. Equivalent damping — $$\zeta \approx \frac{1}{2\,AF}$$ (light damping)

Separation margin, API 617 (9th ed. 2022) Part 1, 6.8.2.9

5. Critically damped — $AF < 2.5$: no separation margin required, $SM_r = 0$

6. Actual margin, below — $$SM_a = 100\,\frac{N_{ma} - N_{c1}}{N_{ma}}$$ N_{ma} = minimum allowable (operating) speed

7. Actual margin, above — $$SM_a = 100\,\frac{N_{c1} - N_{mc}}{N_{mc}}$$ N_{mc} = maximum continuous speed

8. Required, below N_{ma} — $$SM_r = 17\left(1 - \frac{1}{AF - 1.5}\right)$$ $AF \geq 2.5$, Eq. (6)

9. Required, above N_{mc} — $$SM_r = 10 + 17\left(1 - \frac{1}{AF - 1.5}\right)$$ $AF \geq 2.5$, Eq. (7)

10. Acceptance — $SM_a \geq SM_r$ Eq. (5); a critical with $AF \geq 2.5$ inside $N_{ma} \leq N_{c1} \leq N_{mc}$ fails

11. Allowed criticals — $N_{c1} \leq N_{ma}\,(1 - SM_r/100)$ or $N_{c1} \geq N_{mc}\,(1 + SM_r/100)$ (plot bands)

12. 7th ed. option — SM_r not more than 16 % below N_{ma} and 26 % above N_{mc} (API 617 7th ed. 2002, 2.6.2.10)

Sources: Rules 5, 6, 8, 9, 10 and the definitions of $AF_1 = N_{c1}/(N_2 - N_1)$ and N_1, N_2 at 0.707 × peak were read in API 617 9th ed. (2022) Part 1, 6.8.2.9 and Section 3 symbols. **Not confirmed:** the 16 / 26 % caps (rule 12) are from a public summary of the 7th ed., and the % basis above N_{mc} (rule 7) is from the usual reading of Figure 3 (not legible in the copy read). Check them.

Theory check: SDOF (Jeffcott) unbalance response

13. Response — $$X = \frac{e\,r^2}{\sqrt{(1 - r^2)^2 + (2\zeta r)^2}}, \qquad r = \frac{N}{N_n}, \qquad r_{peak} = \frac{1}{\sqrt{1 - 2\zeta^2}}, \qquad X_{peak} = \frac{e}{2\zeta\sqrt{1 - \zeta^2}}$$

Exact half-power AF (root finding on X) compared with $1/(2\zeta)$:

ζ	0.01	0.02	0.05	0.10	0.15	0.20	0.30
AF exact	49.980	24.960	9.900	4.797	3.022	2.073	0.950
$1/(2\zeta)$	50.000	25.000	10.000	5.000	3.333	2.500	1.667

$AF = 2.5$ (the API limit) corresponds to $\zeta = 0.174$ for this response; $1/(2\zeta)$ is within 1 % for $\zeta \leq 0.05$.

Example: $N_n = 3000$ rpm, $\zeta = 0.05$, $e = 0.25$ mil, 600 to 6000 rpm every 40 rpm, $N_{ma} = 4000$, $N_{mc} = 5000$ rpm gives $N_{c1} = 3008$ rpm, $AF = 9.86$ (exact 9.90), $SM_r = 14.97$ %, $SM_a = 24.80$ %: pass. A 2 rpm table matches the exact AF to 0.03 %.

Units and assumptions

Speeds in rpm for both English and metric work. Amplitude: mils or micron (1 mil = 25.4 micron), peak-to-peak or zero-to-peak; the unit only labels the table and plot, since AF and SM are ratios. Use the 1X (synchronous) amplitude from a damped unbalance response analysis or a run-up / coast-down. One critical is assessed at a time: the highest peak in the search range. The data must fall below $0.707\,A_{peak}$ on both sides of the peak. Use the direct input when N_{c1}, N_1, N_2 are read from a plot.

References: API Standard 617, *Axial and Centrifugal Compressors and Expander-compressors*, 9th ed. (2022), Part 1, 6.8.2.9 and Figure 3; 7th ed. (2002), 2.6.2.10. API RP 684, *Tutorial on the API Standard Paragraphs Covering Rotor Dynamics and Balancing* (referred to by API 617 for AF). J. M. Vance, F. Zeidan and B. Murphy, *Machinery Vibration and Rotordynamics*, Wiley, 2010.