Turbine Rotor Surface Thermal Stress during Start-Up

Surface-to-mean temperature difference and thermal stress in a turbine rotor heated at a steady rate, and the largest heating rate for an allowable stress.

Method: Quasi-steady radial conduction and thermal stress in a cylinder

Input parameters

Unit system: SI

Parameter	Value	Unit
Rotor radius (solid) at the section	400.00	mm
Steam/surface heating rate	3.0000	K/min
Rotor steel conductivity	30.000	W/(m·K)
Density	7,800.0	kg/m³
Specific heat	0.56000	kJ/(kg·K)
Elastic modulus at temperature	180.00	GPa
Thermal expansion coefficient	1.3000e-05	1/K
Poisson's ratio	0.30000	
Stress concentration at grooves	2.0000	
Allowable thermal stress	300.00	MPa

Calculated results

Parameter	Value	Unit
Thermal diffusivity	6.8681	mm²/s
Surface minus mean temperature	145.60	K
Peak surface thermal stress	973.44	MPa
Largest heating rate for the allowable	0.92456	K/min

Notes for this case

• Quasi-steady heating of a solid cylinder at rate Ṫ: the profile is parabolic and the surface leads the mean by ṪR²/(8a); the surface stress is K_tEαΔT/(1 − ν) (compressive while heating, tensile on cooling). Start-up curves limit heating rates so that low-cycle fatigue life is respected; bored rotors and thick casings need their own geometry factors.

Formula and method

$$\Delta T_{s-m} = \frac{\dot{T} R^2}{8a}, \quad \sigma_s = \frac{K_t E \alpha \Delta T_{s-m}}{1-\nu}, \quad \dot{T}_{max} = \frac{8a\sigma_a(1-\nu)}{K_t E \alpha R^2}$$

Variables

R	Rotor radius (solid) at the section	m
$\dot{T}$	Steam/surface heating rate	K/s
k	Rotor steel conductivity	W/(m·K)
ρ	Density	kg/m³
c_p	Specific heat	J/(kg·K)
E	Elastic modulus at temperature	Pa
α	Thermal expansion coefficient	1/K
ν	Poisson's ratio	-
K_t	Stress concentration at grooves	-

σ_a	Allowable thermal stress	Pa
a	Thermal diffusivity	m²/s
ΔT_{s-m}	Surface minus mean temperature	K
σ_s	Peak surface thermal stress	Pa
$\dot{T}_{max}$	Largest heating rate for the allowable	K/s

Method and standards

Rotor stress.

Assumptions and limits

- Solid cylinder; quasi-steady heating; constant properties.

References

Quasi-steady radial conduction and thermal stress in a cylinder

Report details

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Results are for engineering estimation. Verify critical designs against the referenced standards and your own data.

This calculator online

https://calc.firecad.com/boilers-power-plant/steam-turbines/rotor-thermal-stress-startup

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Reopens the calculator with the inputs of this report.