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Steam Turbine

Life time calculations and life limitings factors

Göteborg 2017

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AGENDA

- **Intro - Life time calculation (theory)**
- Steam turbine start up and shut down
  - Limitations
  - Improvements real examples
- Life limiting factors during turbine life time
  - Life time assessment (LTA)

Life time calculations
Limitations/Influence

Blades/diaphragms

erosion/corrosion

Pressure differences

Inlet steam

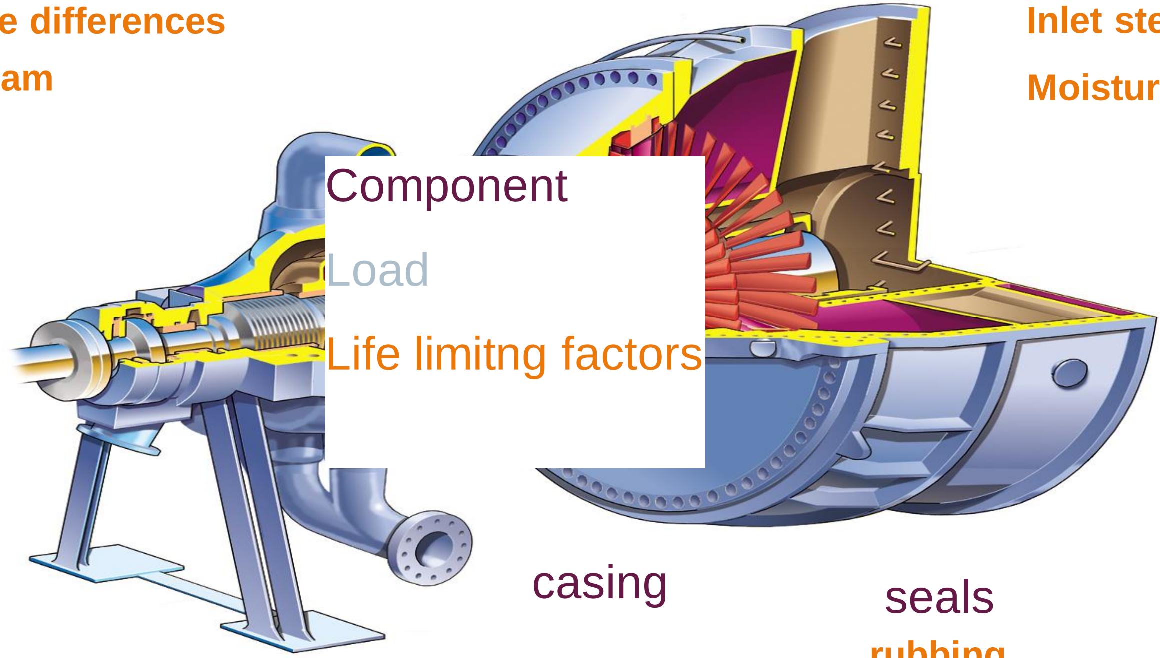
Speed

Final stages

Water droplet erosion

Inlet steam

Moisture content



Component

Load

Life limitng factors

axis

Type of loads:

Static

thermal

dynamic

casing

Temperture

Temperature gradient

Pressure

seals

rubbing

Life time calculations
Basic criteria

The steam turbine should be able to handle all loads that it might be exposed to during the design lifetime without inaplicable deformations and brott apperas.

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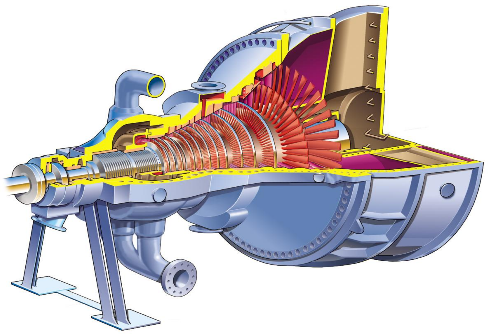
Life time calculations
Load profile

Thermal transients,

Static load

and

Dynamic load



Safety and life time aspects

Typical load profil

- Start – full load - stop

  ~ 2000 - 10000 cycles

  100 000 – 200 000 EOH

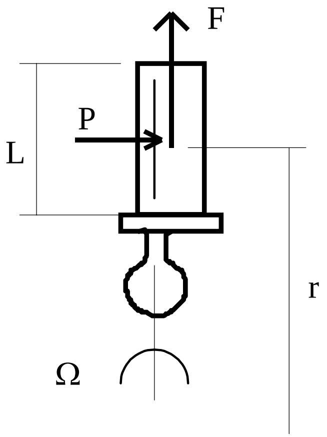
  Metal temperaturer -30 - 585 C

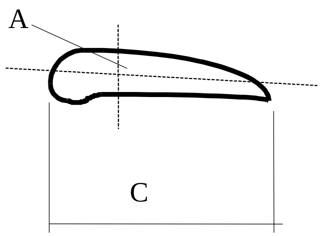
- Vibrationer

Real loads verified by

- Lab test
- Prototyp testing
- Operational experience (RDS)
- LTA

Life time calculations
Static load on a turbine blade





För en skovel enligt figur fås spänningen på grund av

Centrifugal last

$$\sigma_c = F / A \sim \rho L r \Omega^2$$

böjspänning på grund av statisk gaslast

$$\sigma_b = M_b / W_b \sim P L / (z C^3)$$

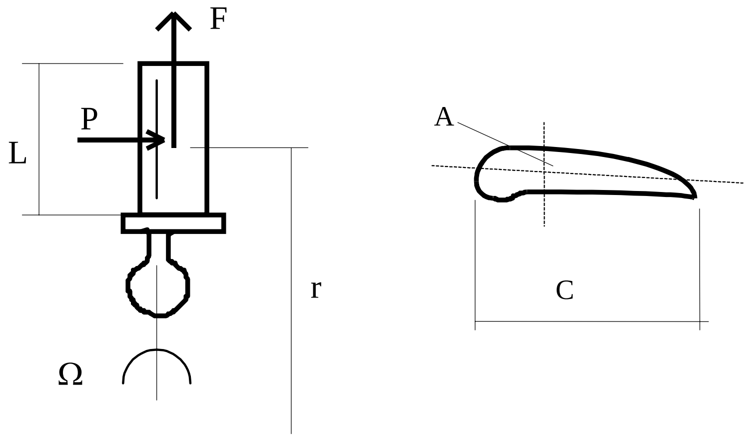
Termisk last

$$\sigma_t \sim \alpha \Delta T$$

Ω = rpm, P = gas load and z = no. of blades.

T = temperature, α = thermal elognation

Life time calculations
Dynamic load on a turbine blade



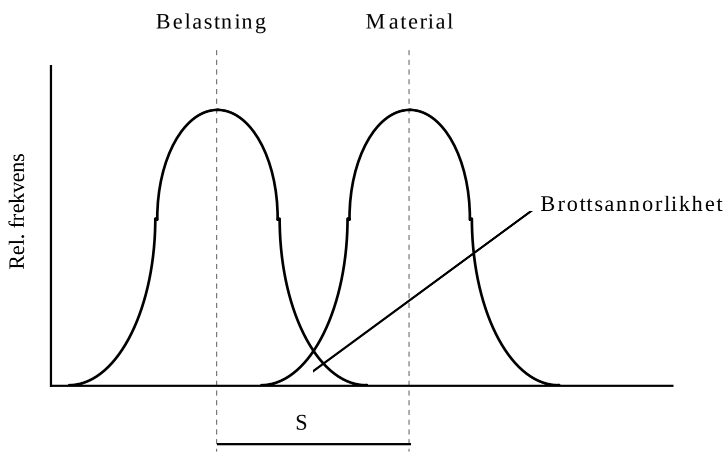
The load on the blade can be general described as

$P(t) = P_m + P_a \sin(\omega t)$

$\sigma_a = S H_n A \pi / \delta \sigma_m = D_n \sigma_m$

Dynamic factor depends on type of stage design

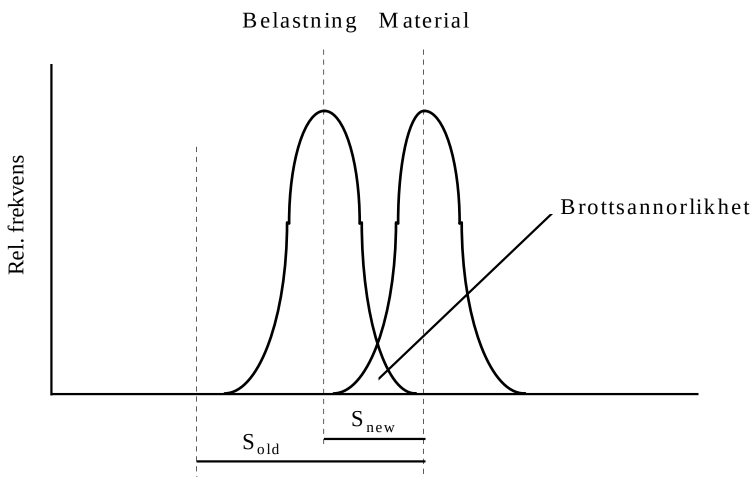
Life time calculations
Statistisk brottsannolikhet



Uncertainties

- Load
- Calculation tool
- Manufacturing

+ Material data



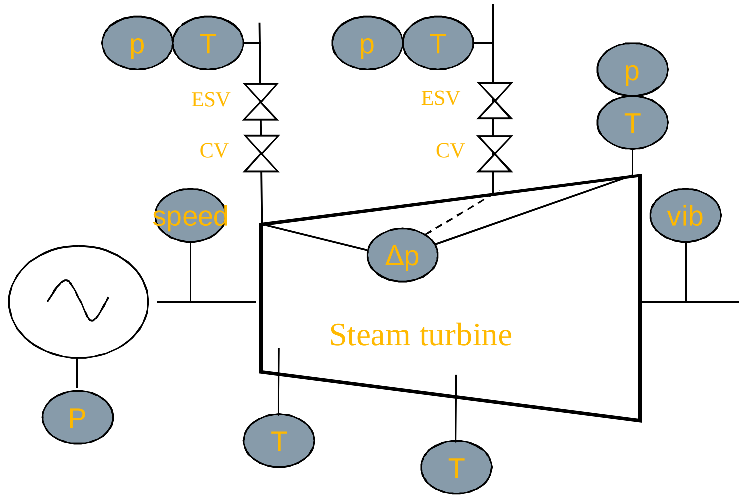
How can turbine operation be controlled?

What needs to be controlled?

Power/frequency control
with admission steam valves

Steam parameter control

Operation limitations for turbine protection



P: Power; p: pressure, T: temperature

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  - Improvements real examples
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Steam turbine start up and shut down
Typical number of starts per year

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We thought

Base load

- 3 cold starts per year
- 6 warm starts per year
- 22 hot starts per year

Peak load

- 5 cold starts per year
- 50 warm starts per year
- 200 hot starts per year

Solar plants

- 20 cold starts per year
- 340 warm starts per year
- 20 hot starts per year

Reality

Base load

- 3 cold starts per year
- 6 warm starts per year
- 22 hot starts per year

Peak load

- 50 cold starts per year
- 125 warm starts per year
- 100 hot starts per year

Solar plants

- 120 cold starts per year
- 200 warm starts per year
- 5 hot starts per year

Steam turbine start up and shut down
Start up category

Start category (cold, warm, hot) is chosen based on casing temperature

The start up category depends on stand still time between starts, surrounding temperature, status on insulation etc

Steam turbine start up and shut down
Start up- What are the challanges

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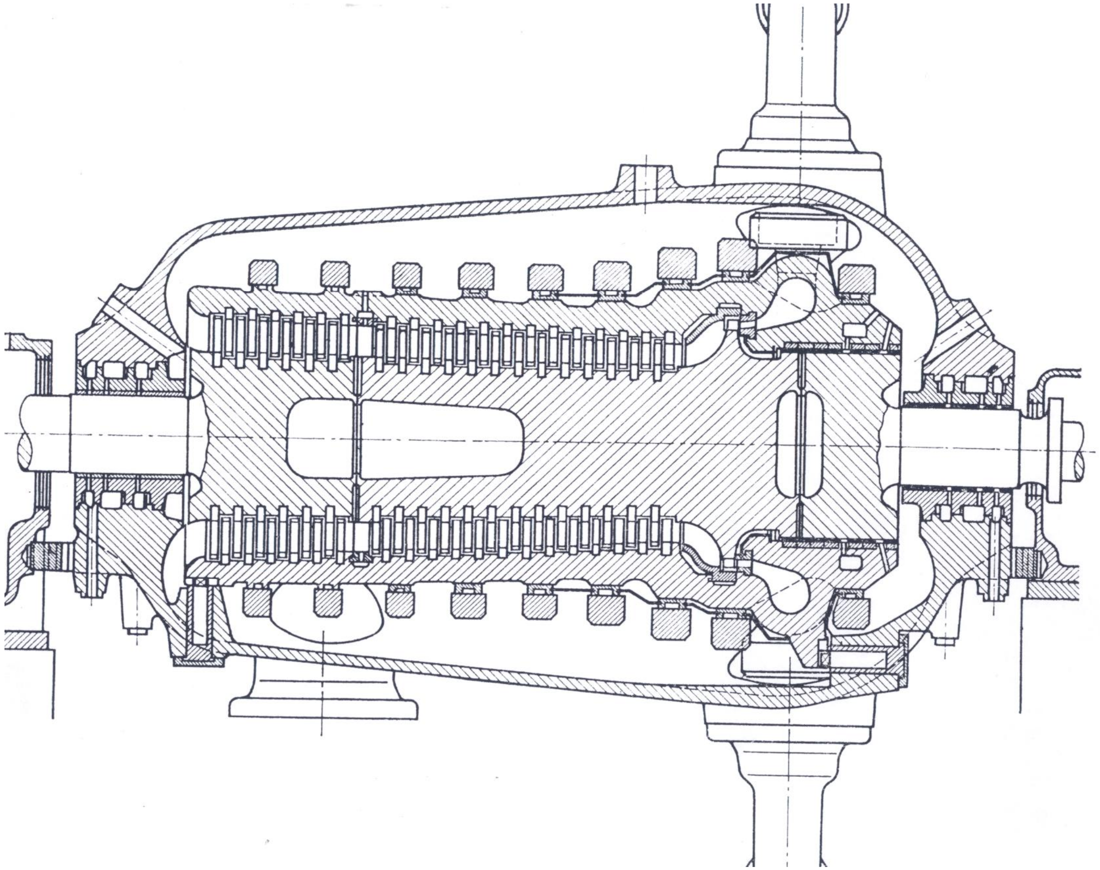
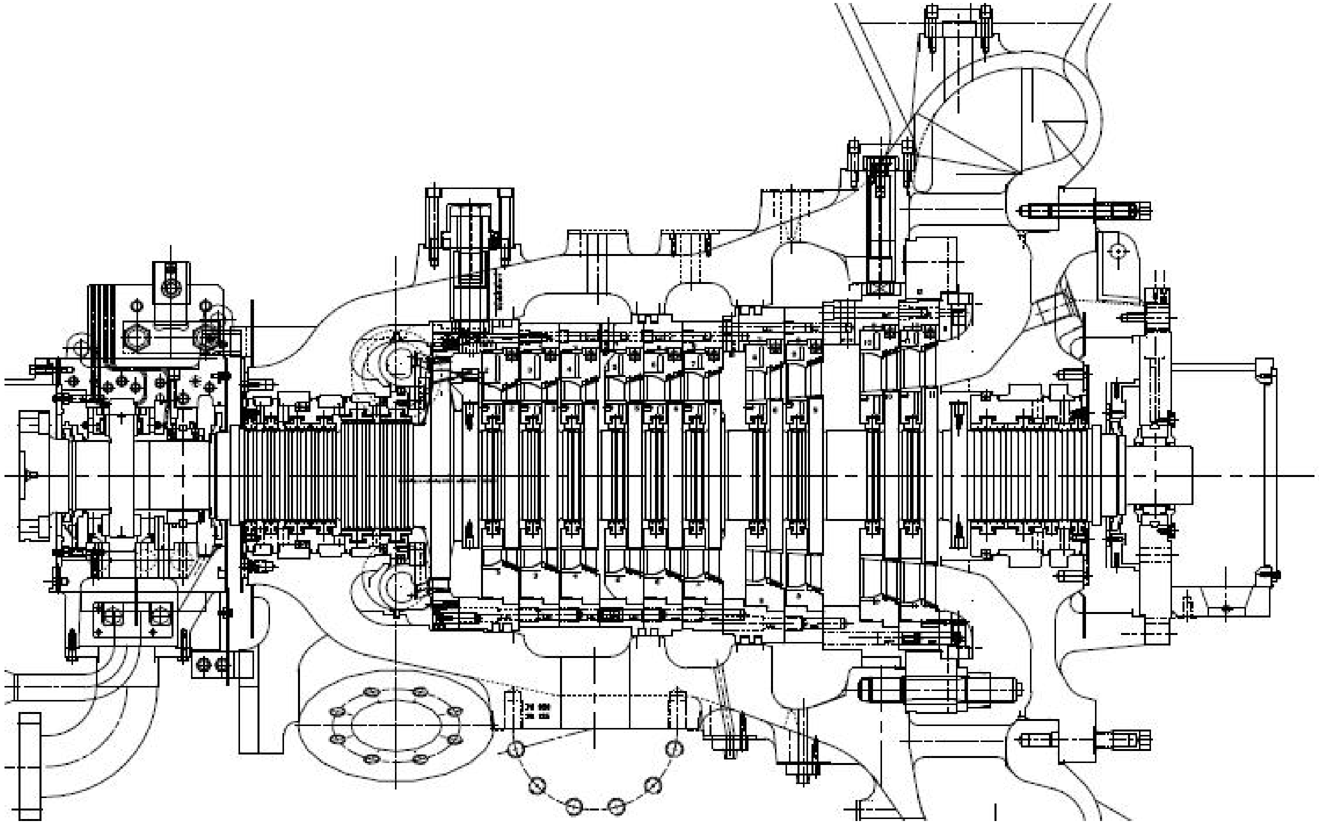
Large centrifugal loads (static)	LP
Bending/torsion loads	LP
Large thermal loads (LCF, creep)	HP, IP
Material properties	HP, IP
Unsteady steam loads (HCF)	HP, IP, LP
Stress concentration in notches	HP, IP, LP
Corrosion	LP
Erosion	LP
Oxidation	
Rubbing	IP, LP

Steam turbine start up and shut down
High pressure reaction steam turbine with control stage



Steam turbine start up and shut down
High pressure impulse steam turbine with control stage

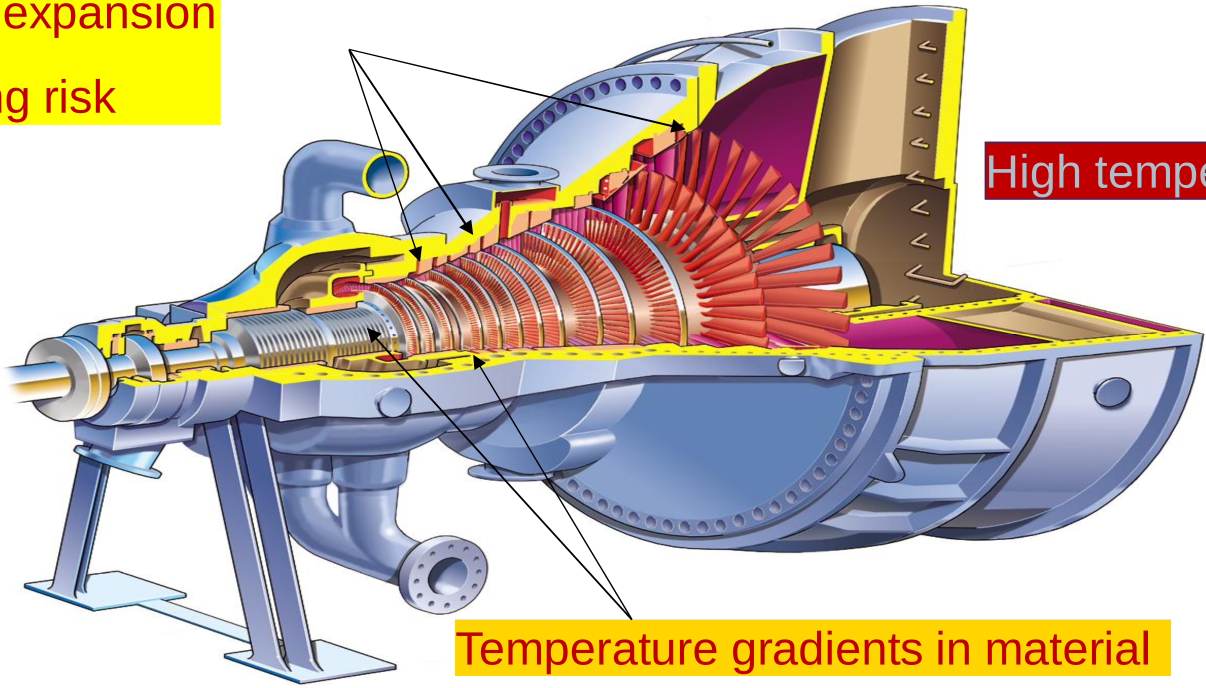


Steam turbine start up and shut down
Specific limitations

Start up = operation with specific limitations

Thermal expansion

-> rubbing risk



High temperature in exhaust

Temperature gradients in material

Thermal stress

Material fatigue

Steam turbine start up and shut down
Steam turbine start up time

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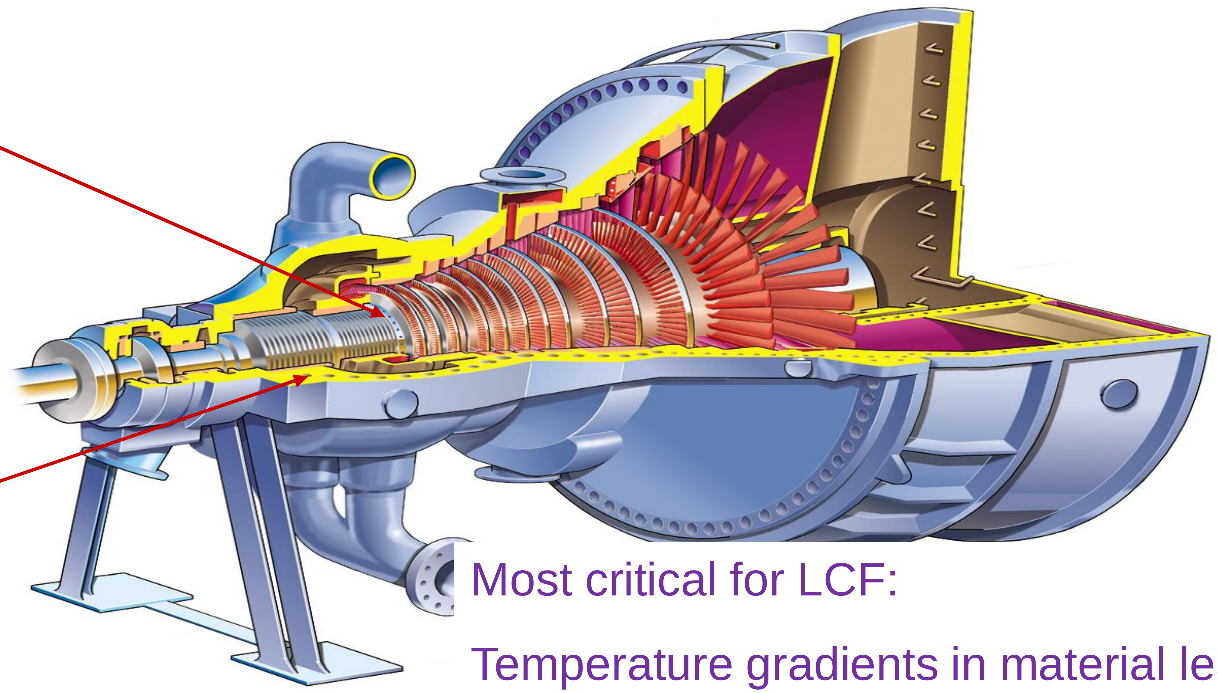
Limited by allowed thermal stresses and clearances

Dependent on

- Inlet steam data
- Control concept
- Turbine size and design
- Material

Steam turbine start up and shut down
Which parts are most critical for thermal fatigue during start ?



rotor inlet region

Inlet casing flange

Most critical for LCF:

Temperature gradients in material lead to local plastic strain at fillets or notches

Steam turbine start up and shut down
Concept of linear life consumption

$$\sum \frac{N}{N_F} + D_{Creep} \leq 1 - (\text{safety} \quad \text{margin})$$

N: Number of cycles

N_F: Number of cycles until crack initiation due to LCF (temperature dependent)

N/N_F: LCF –damage (Palmgren –Miners linear damage rule)

D_{creep}: Creep damage (for temperatures T > T*)

Steam turbine start up and shut down
LCF material data (example)

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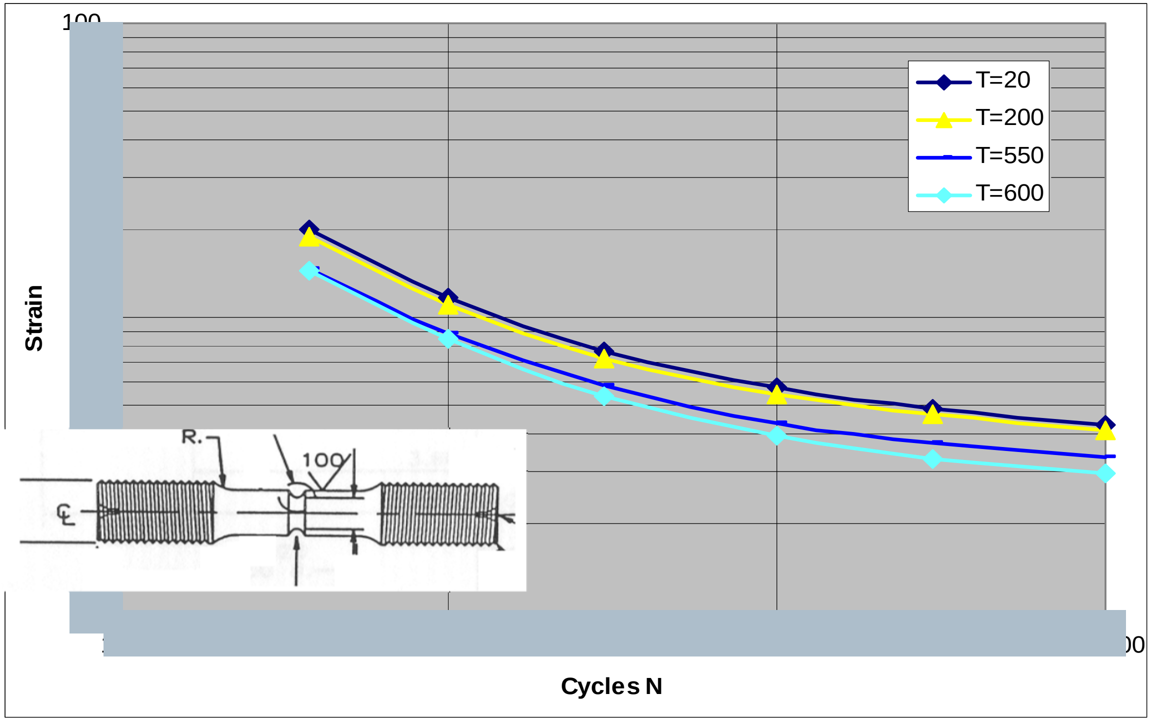


This is not the material situation in reality!

Estimated under well defined conditions

- -Load direction
- -Load cycles
- -Geometry
- -Temperature …

Statistical evaluation

Steam turbine start up and shut down
Simplified thermal stress and strain during start

General

$$\varepsilon = \beta \cdot \Delta T$$

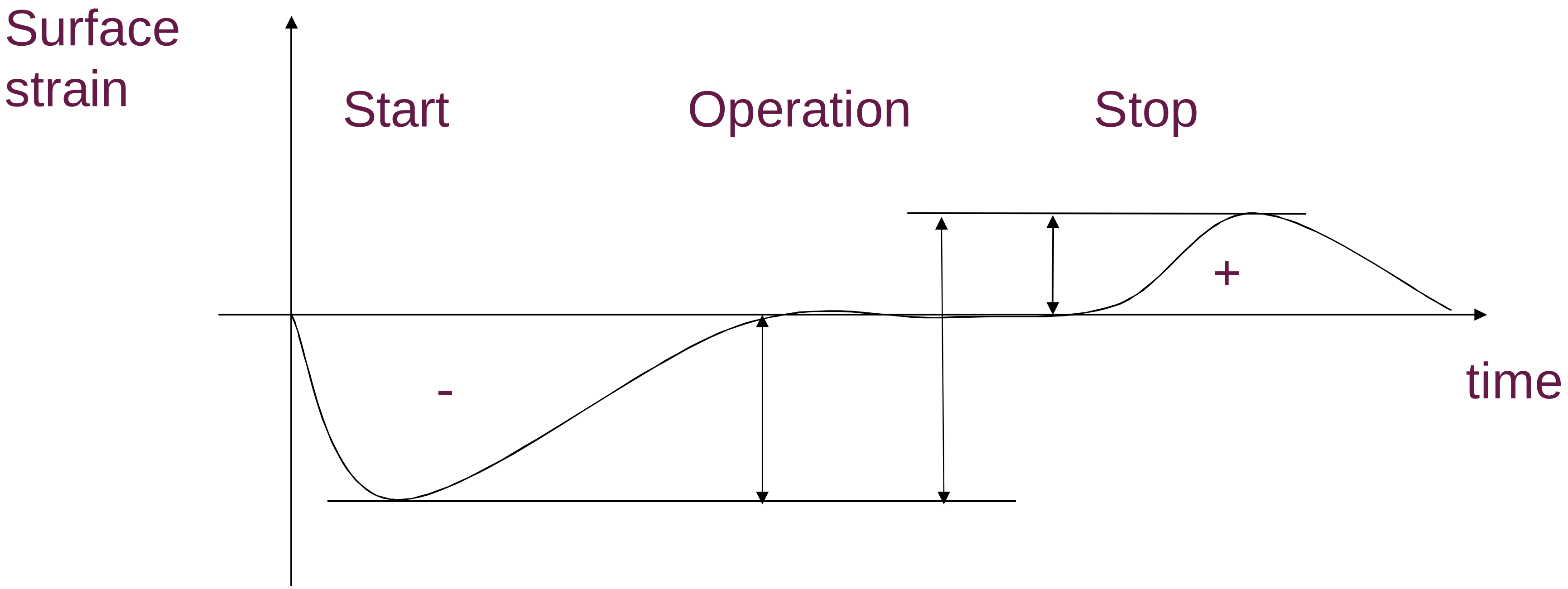
β: thermal expansion coefficient

Radial strain
- expansion outwards
- largest stress in center of body (tensile)
- zero stress at outer wall

Tangential strain
- strain prohibited in outer region →compressive stress
- Less strain in the colder inner region →tensile stress

Axial strain
- Strain prohibited in outer region →compressive stress
- Less strain in the colder inner region →tensile stress

Steam turbine start up and shut down
Start / stop cycle



Steam turbine start up and shut down
Simplified: Axial stress model

$$\sigma = E \cdot \varepsilon = E \cdot \frac{\beta}{1-\nu} \cdot \Delta T$$

An allowed stress can be expressed as an allowed temperature difference:

$$\Delta T = T_i - T_m < \Delta T_{allowed}$$

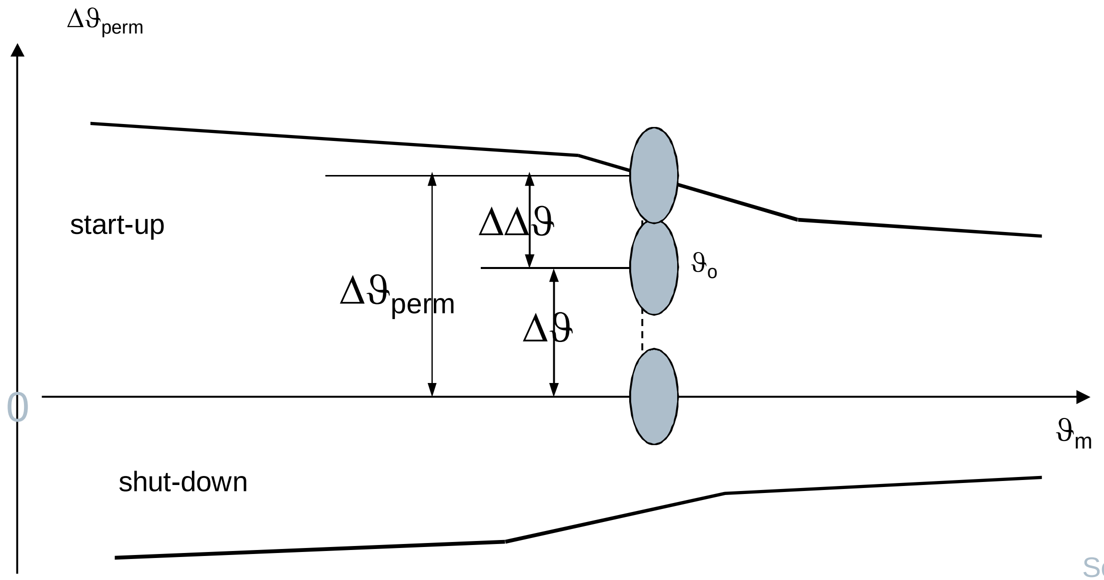
Temperature distribution in

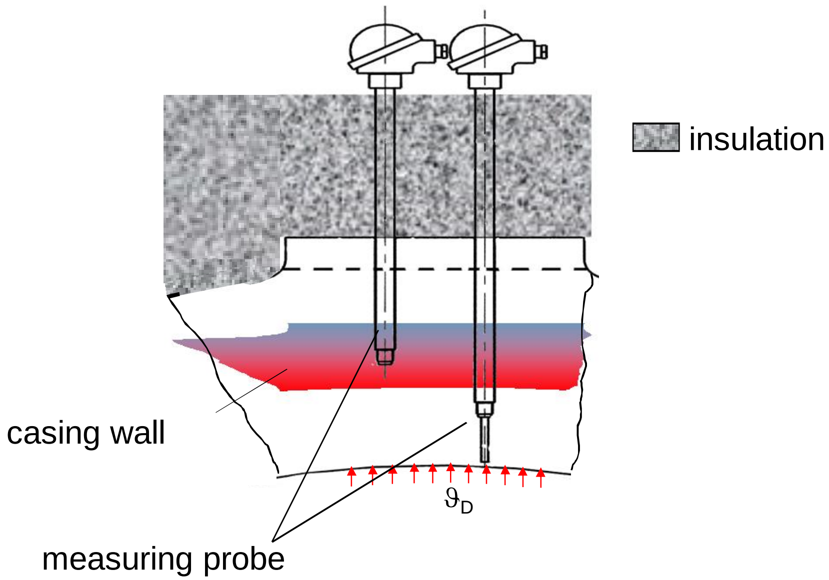
Material needed!

Steam turbine start up and shut down

Thermal stress control

- measure temperature differences for thick walled components
- simulation for shaft temperatures
- influence on automatic start-up program





Source: internal communication with LSU, 2013

Examples:
Design to reduce thermal stresses

Reduce material thickness (Barrel design)

Preheat , keep turbine warm

Optimize start up transients (stress evaluator)

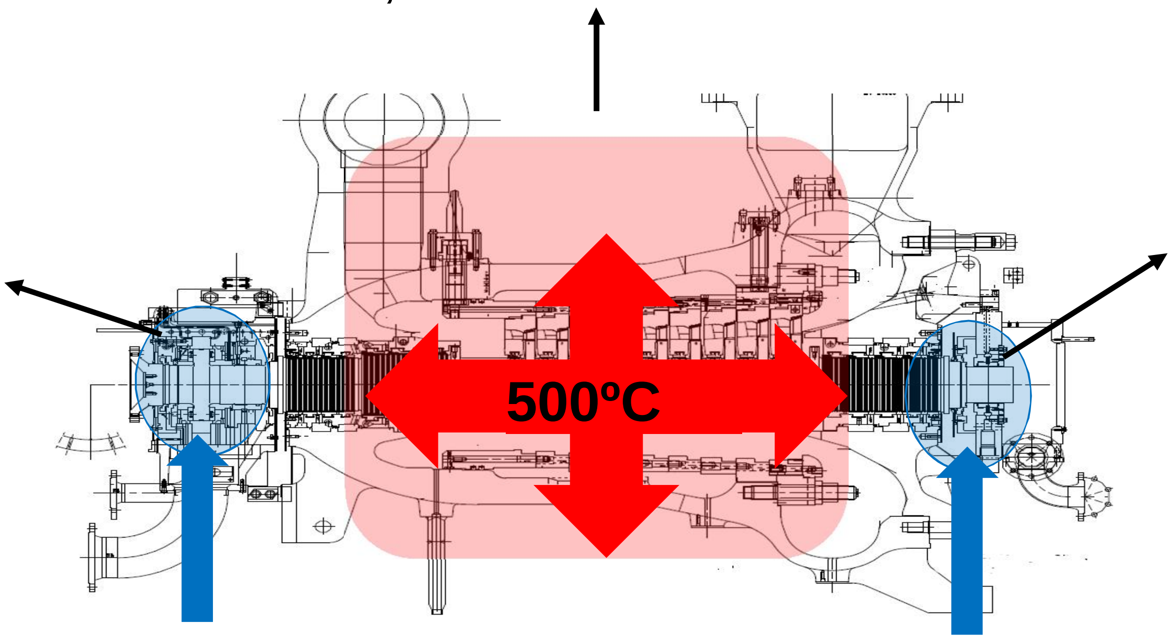
Optimize material use (locally better material)

Improving start up time
Heat losses HP

Where does the heat go?

Temperature through convection depending on surrounding temperature, insulation condition, wind, etc

Oil needed for bearing lubrication constant temperature 40-60C



Oil needed for bearing lubrication constant temperature 40-60C

Improving start up time
Heat losses LP

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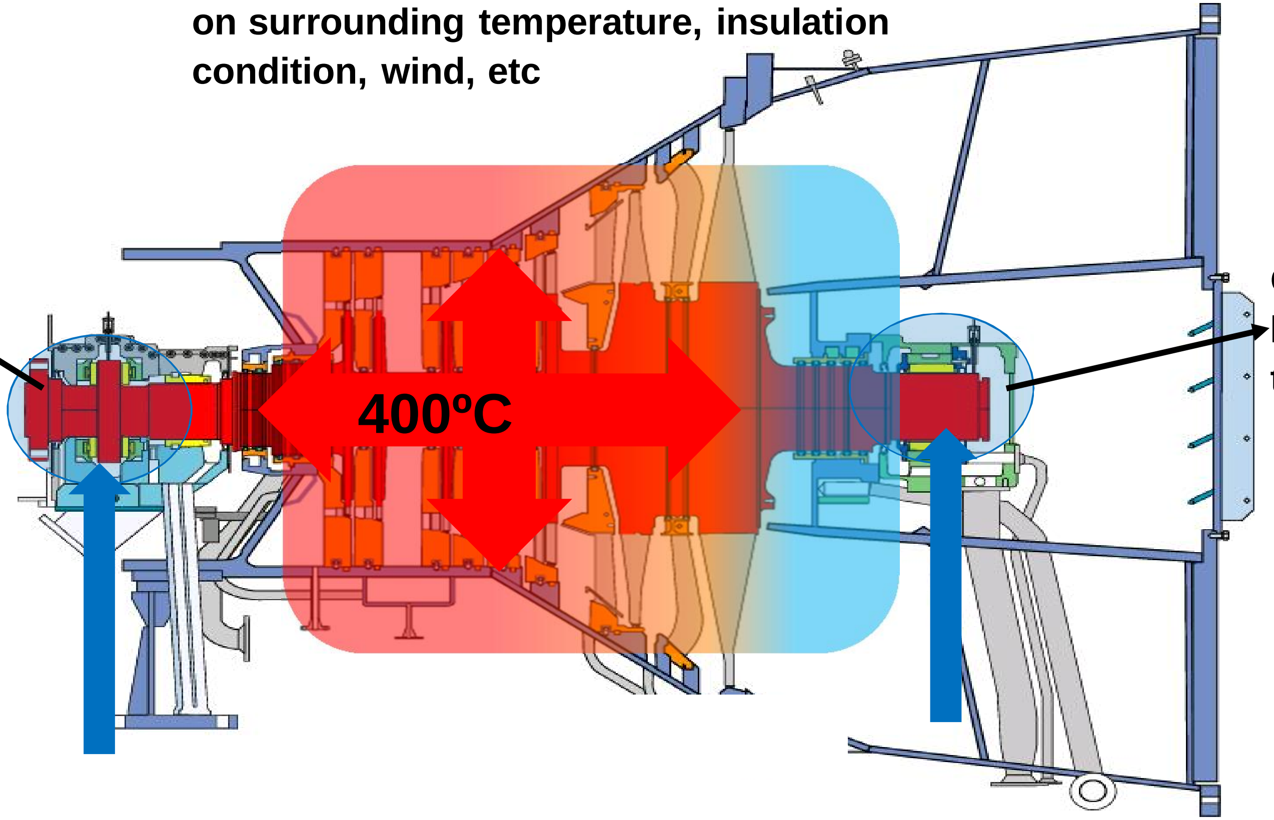

Oil needed for bearing lubrication constant temperature 40-60C

Improving start up time
What is needed?

Heating blankets casing

Gland steam

Axial displacment transmitters

Improving start up time
Heating blankets

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- 5 Zones that will keep the turbine casing warm
- Gland steam to keep the rotor warm
- Supervision of thermal elongation between rotor and casing:
  - No rubbing between stator and rotor
  - Equal temperature between casing and rotor

Improving start up time
Heating blankets

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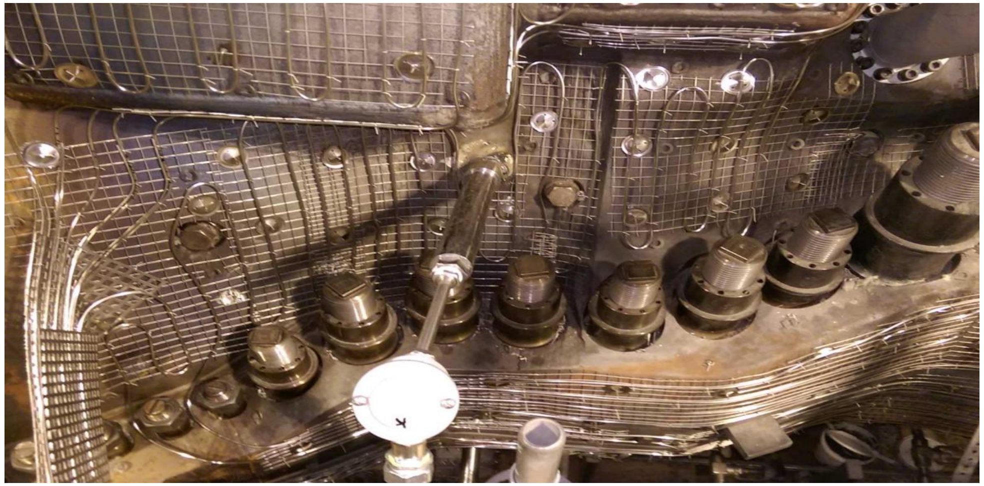
- 4 Zones that will keep the turbine casing warm
- Gland steam to keep the rotor warm
- Supervision of thermal elongation between rotor and casing:
    - No rubbing between stator and rotor
    - Equal temperature between casing and rotor

Improving start up time
Heating blankets

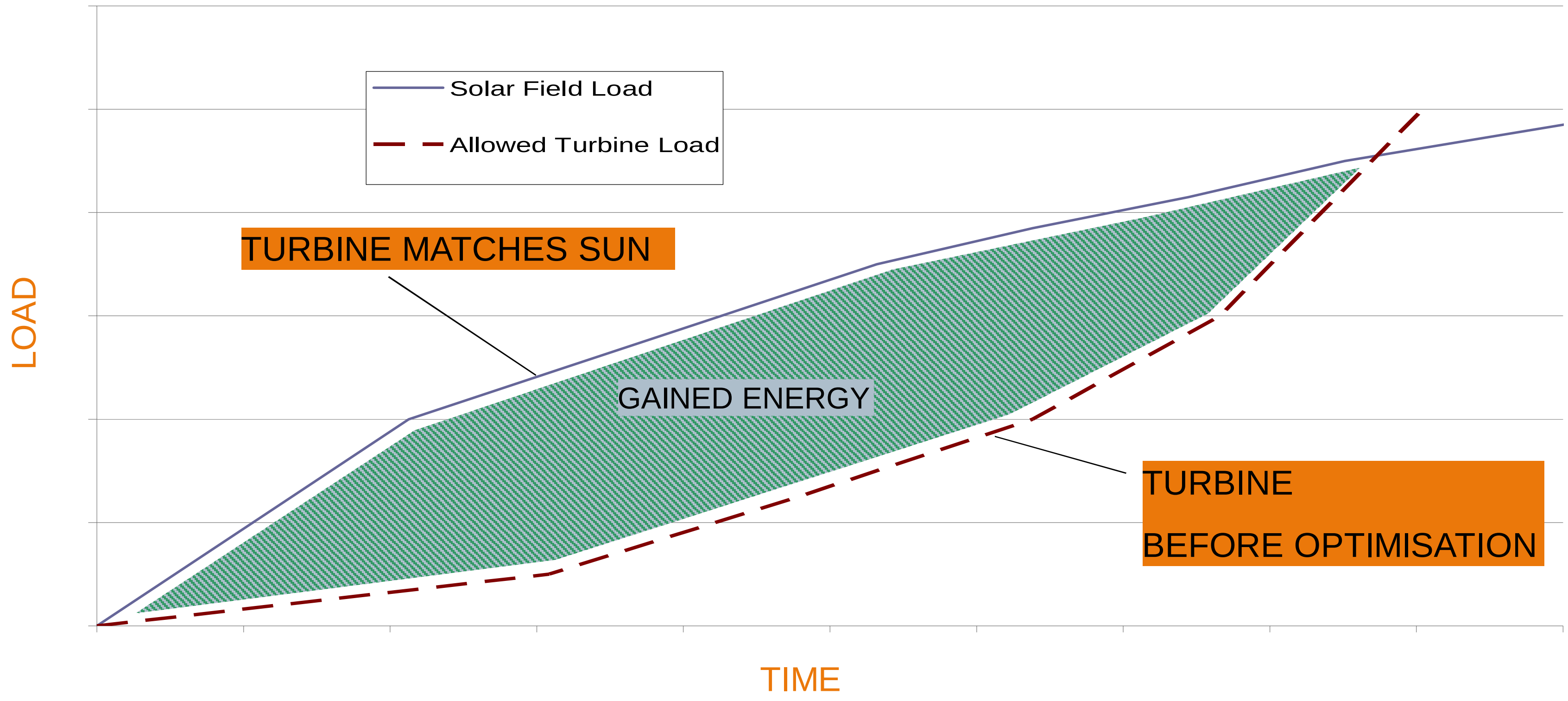


Improving start up time
Example

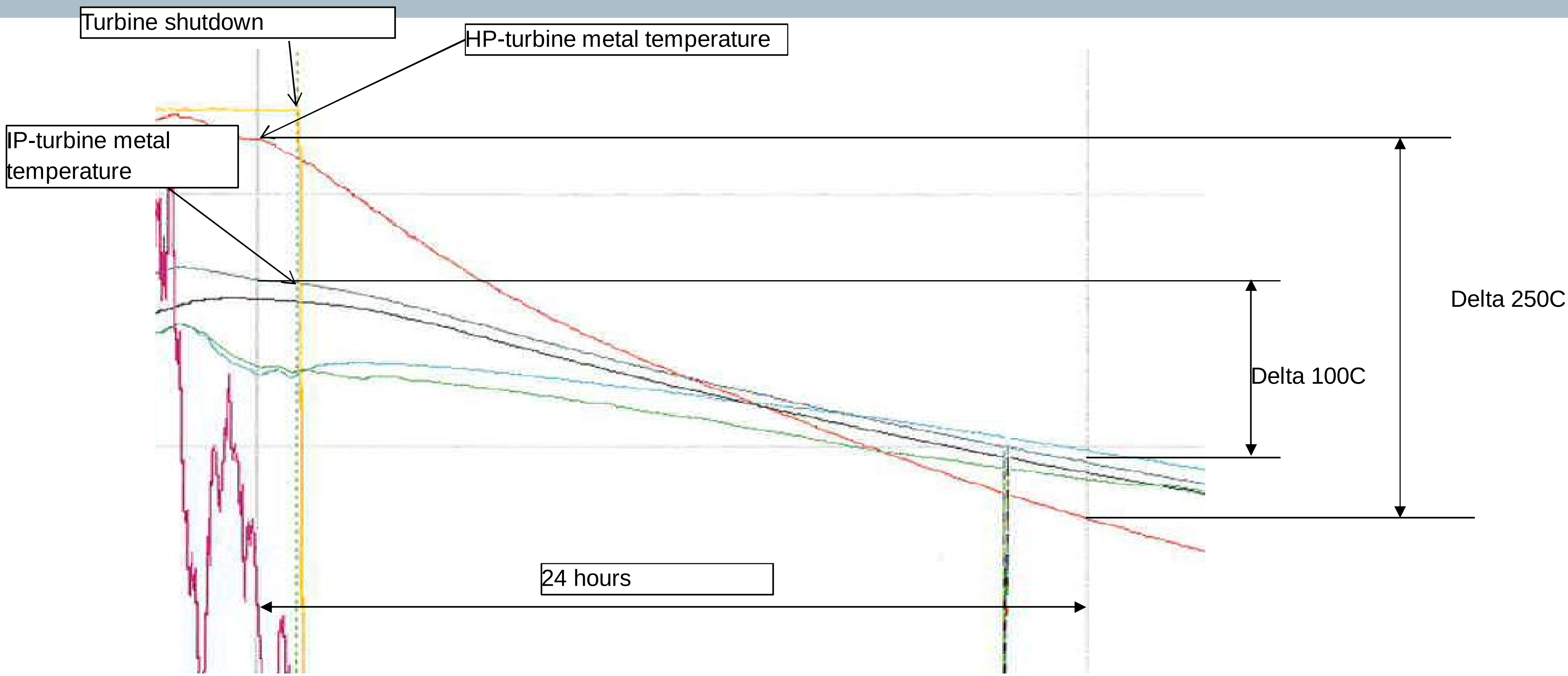
CSP

(Concentrated Solar Power)

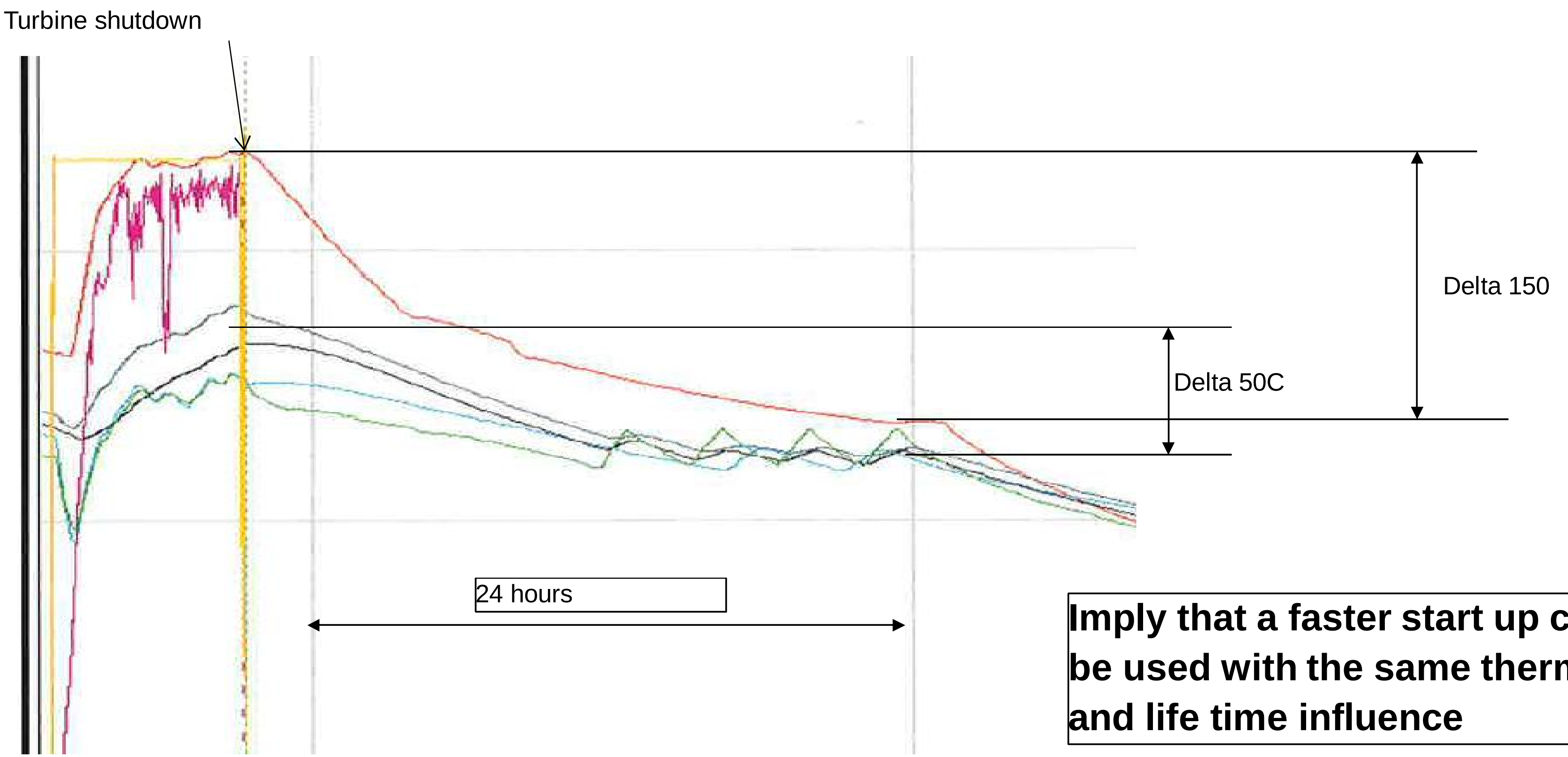
Improving start up time
Why?



Improving start up time
Before installation



Improving start up time
After installation



Imply that a faster start up curve can be used with the same thermal stress and life time influence

Forced cooling
What is needed

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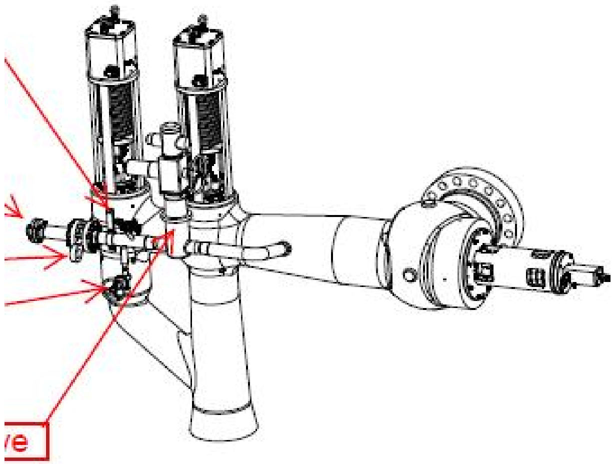
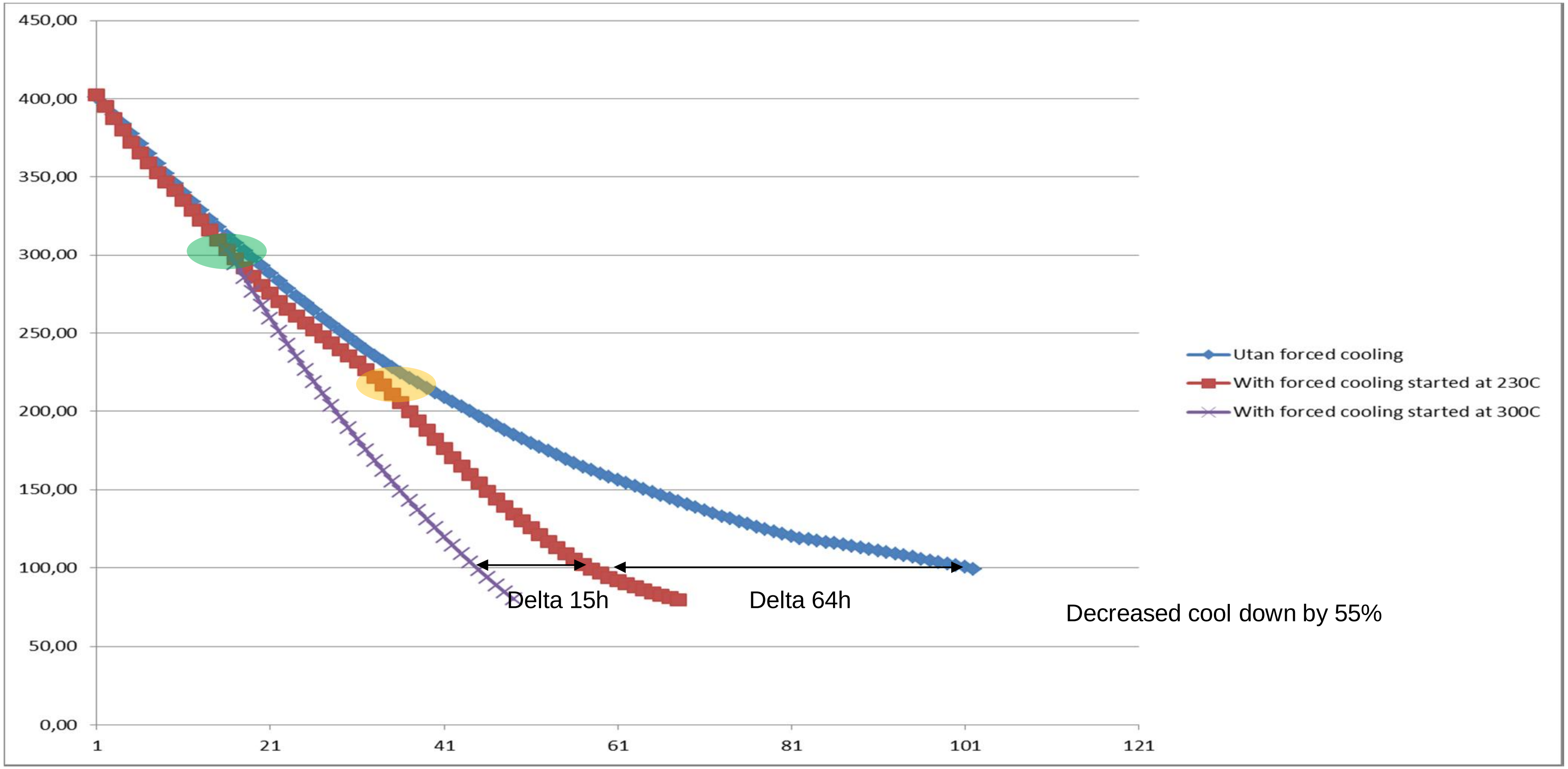


Axial deplacement transmitters

Forced cooling
Out come



Thank you for your attention!

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