Clic Workshop 2009

Thermo-mechanical conditions of the CLIC module

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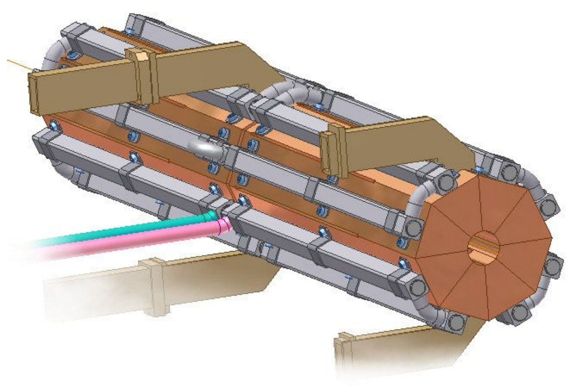
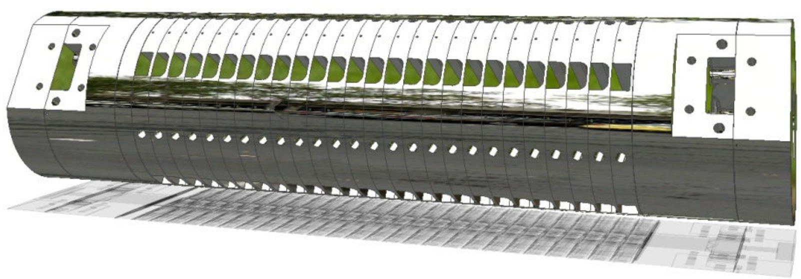
Introduction and Content

- Motivation
- Thermal load sources
- Preliminary operation conditions for the simulation
- Recall of module cooling baseline
- Cooling specifications for the AS and the PETS
- Towards thermo-mechanical model
- Conclusions





Motivation – Why ?

- We have details on most components' mechanical behavior

  How to combine them?

- Idea is to unite the different components' individual behavior into uniform integrated model that describes the behavior of a module or its subsystem during different operation conditions

Motivation – What should come out?

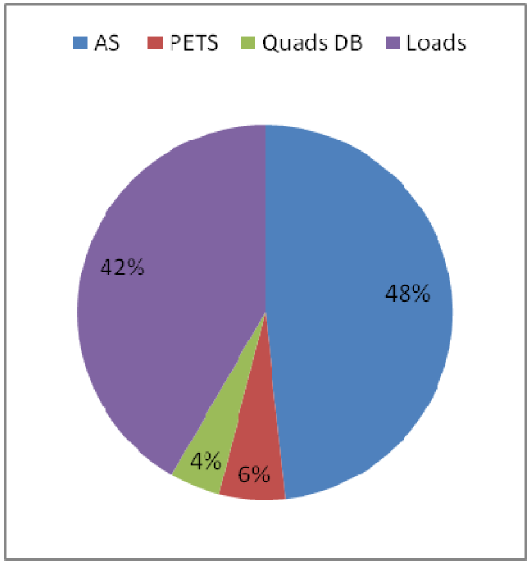
1. **In practice,** a systematic simulation study process.
2. Increase of understanding on mechanical behavior of the module and systems

   → <u>What happens, when and why</u>
3. Thermal response of the transitions between operation modes

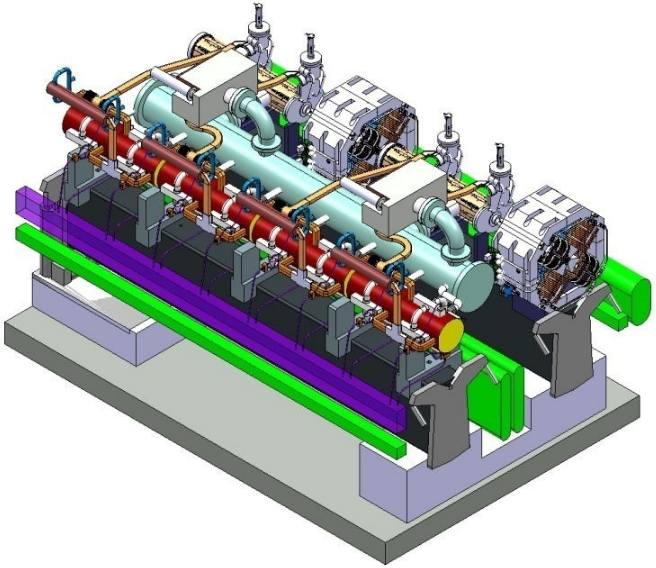
The first steps are being shown

Thermal load sources

- Power Dissipations
  - AS ~ 412 W
  - PETS ~ 110 W
  - Load ~ 712 W
  - DB Quad ~ 148 W
  - MBQ = 2 x AS + Load (reservation)
  - Module ~ 7.7 kW (type 0)
  - Linac ~ 65000 kW (all types)



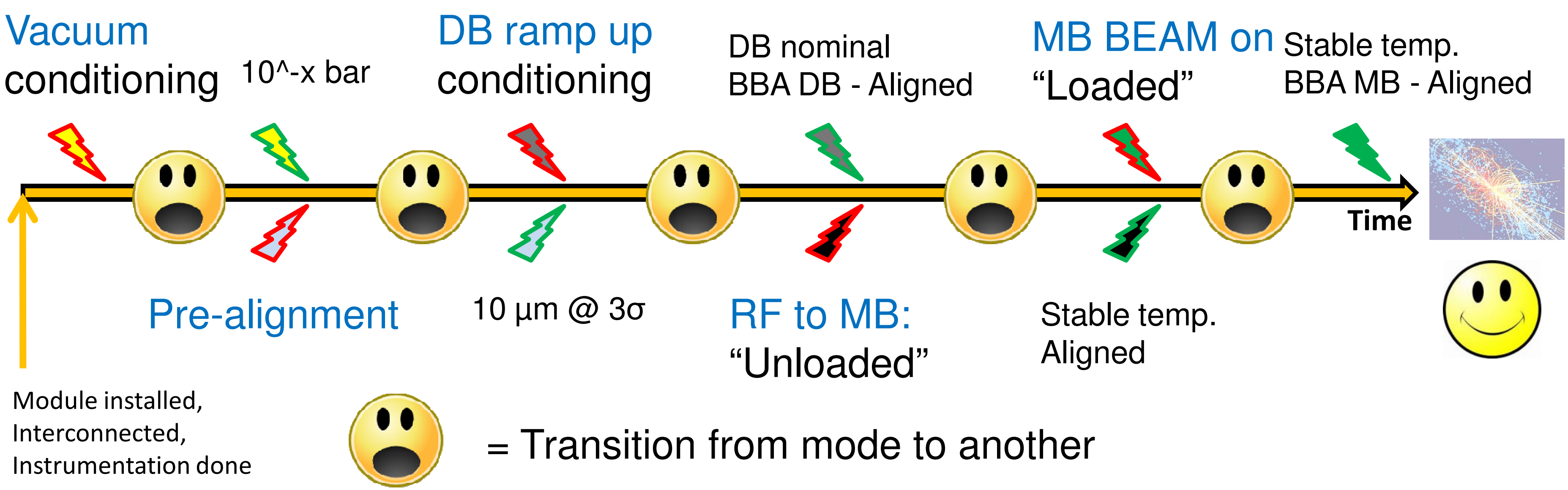
Type 0



- Cooling circuits
  - Circuit A – Module components
  - Circuit B – Other components
- Ventilation system
  - Transversal ventilation

Preliminary operation conditions

One ramp up process of an module from thermo-mechanical point of view



Thermal response between operation conditions?

Mechanical response due to transition from mode to another – significant effect?

N.B. According to latest information pilot beam can be fed to main linac when 90 % of RF is delivered to MB

AS and PETS cooling specifications

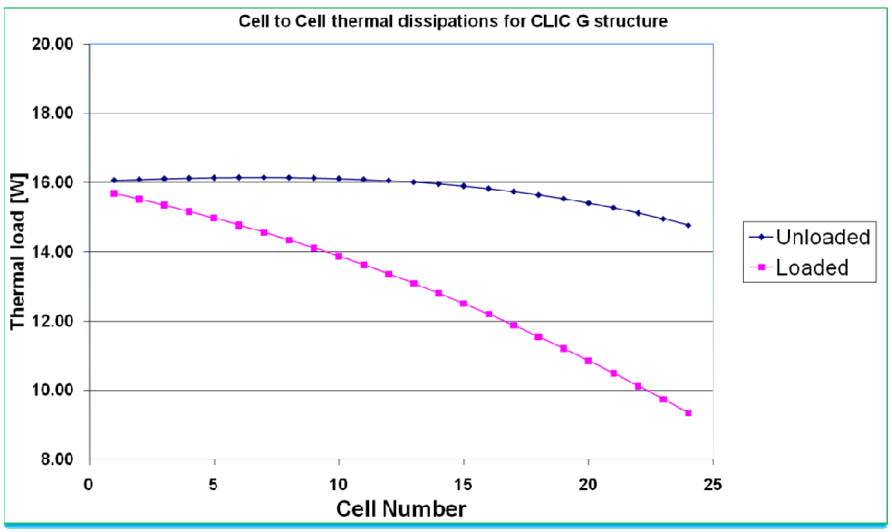
- AS
  - Is available in EDMS 964717

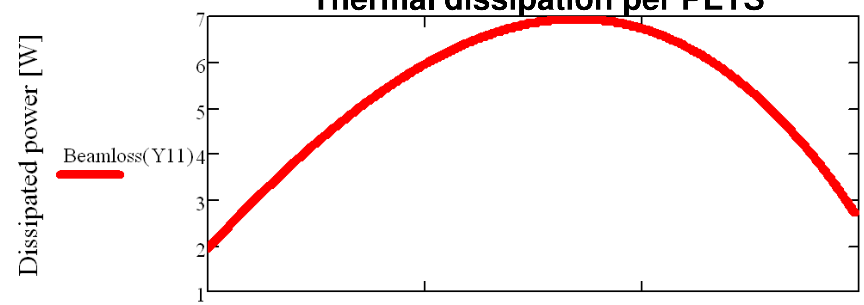
  <u>Some key points:</u>
  - Sustain alignment of few microns
  - Design the operation temperature in parallel to RF-design
  - Consider unloaded condition and loaded condition
  - Consider RF-power variation in AS

- PETS
  - Is available in EDMS 964715

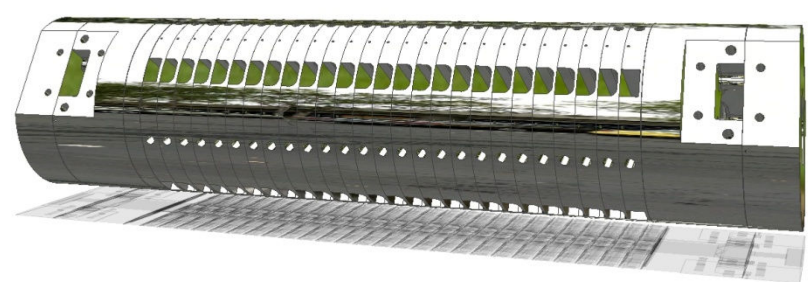
  <u>Some key points:</u>
  - Sustain alignment of ~20 microns
  - Consider steady state beam losses (0.5 %) and surface currents, falling on one octant

Thermal cell-by-cell dissipation distribution in an accelerating structure





Over DB sector

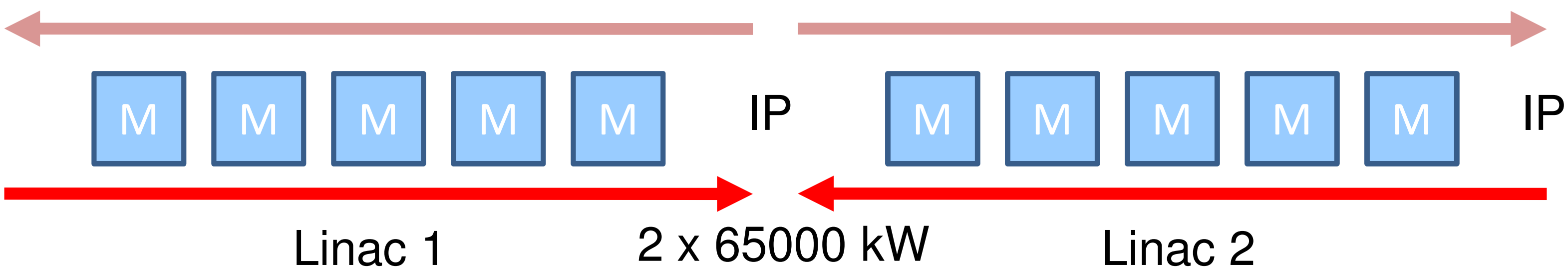


Nb. Thanks to R. Zennaro, A. Grudiev and I. Syratchev

Recall of module cooling baseline

Circuit A

Structures are cooled in parallel with an uniform duct over a certain length of a linac.
Demineralised water



Baseline configuration

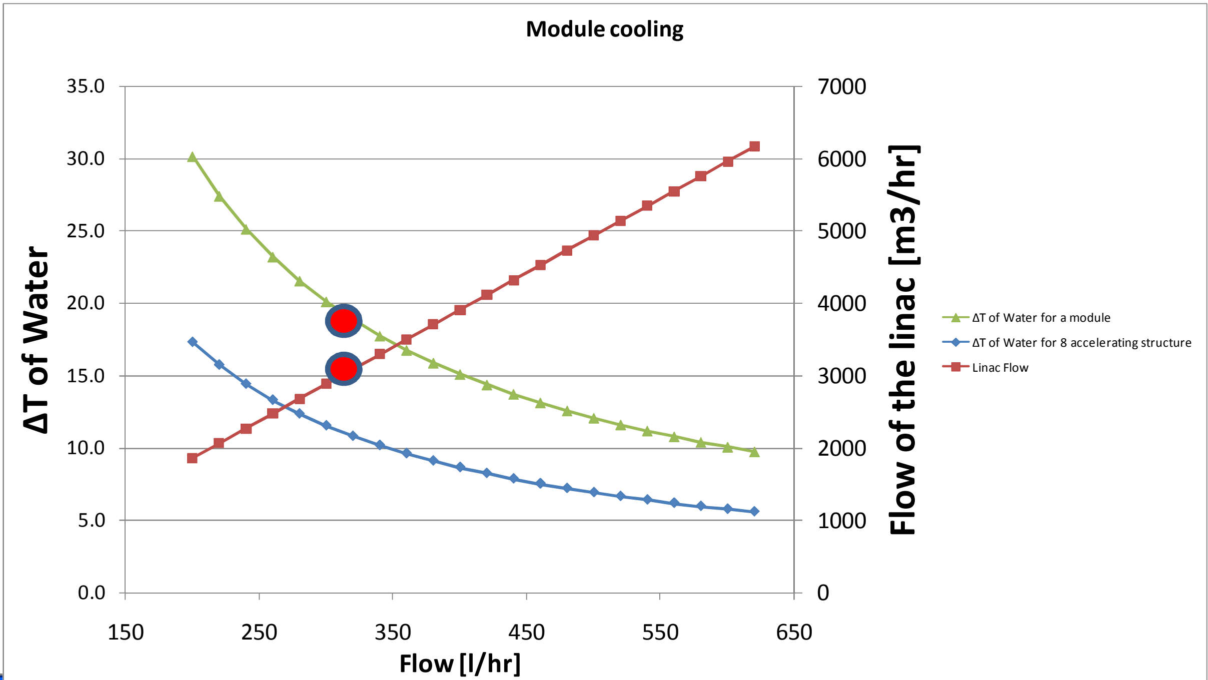
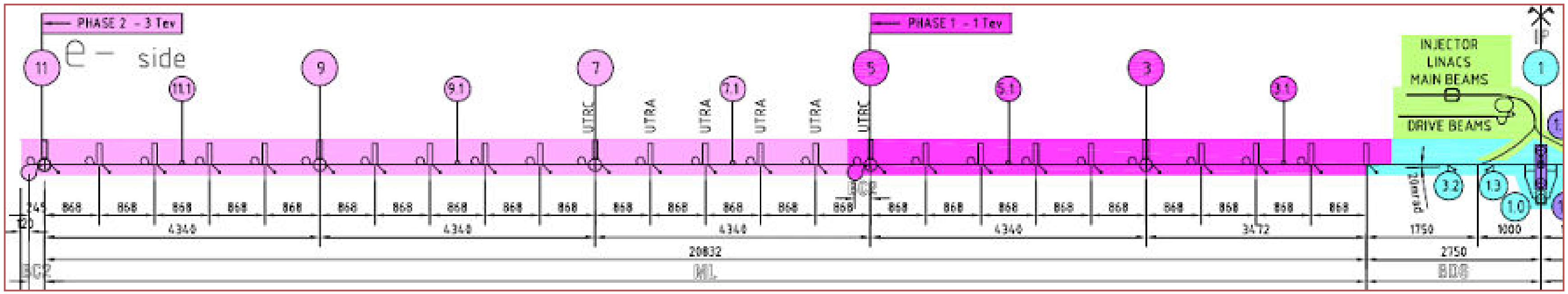


Illustration of module flow's
Effect on ΔT of water and
overall flow of a linac.

Module cooling baseline



Baseline configuration

Flow / Linac: 3100 m^3/hr

Flow / Module: ~340 m^3/hr

$\Delta T_{linac} = \Delta T_{module} = 17.5$ K

$\Delta T_{AS} = 10.2$ K

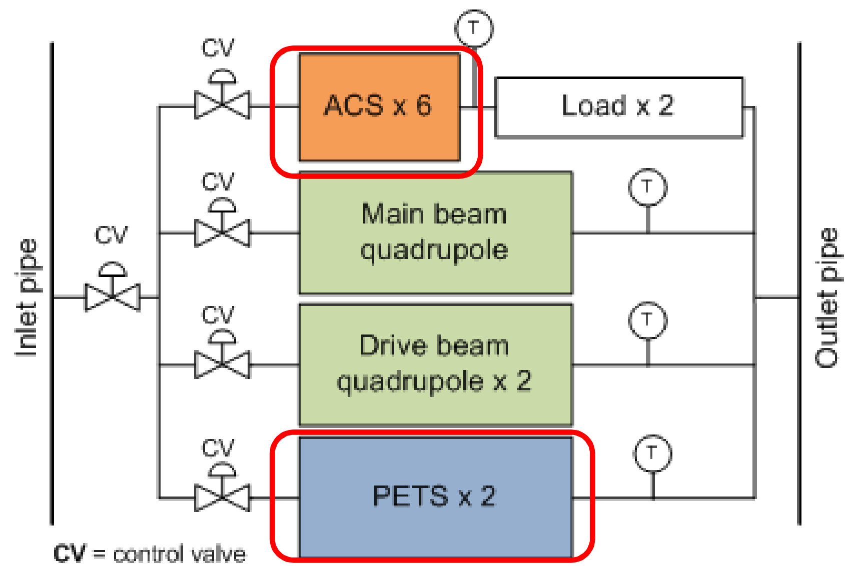
$\Delta T_{PETS} = 10.2$ K

$\Delta T_{DB\_Q} = 10.2$ K

$\Delta T_{Load} = 8.9$ K

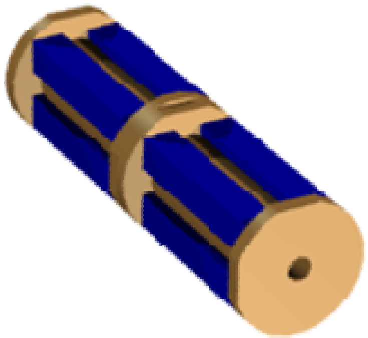
$\Delta T_{MB\_Q} = 6.3$ K

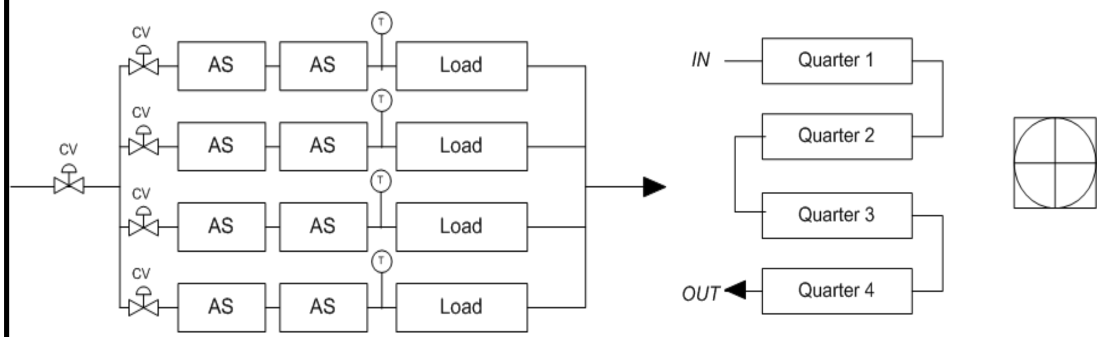
$T_{In} = 25$ ºC



CV = control valve
T = temperature sensor

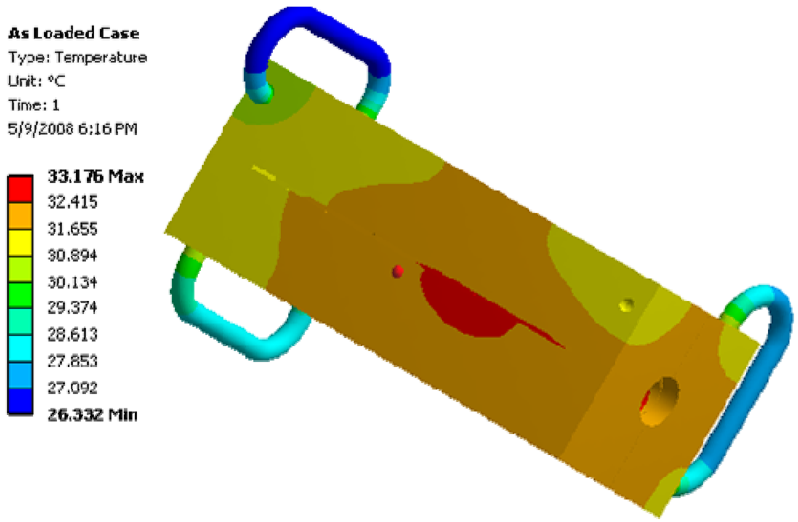
Module cooling baseline - AS





1^{st} ACS: Tin = 25C, flow 69 l/hr

<u>Baseline of the routing</u>



Cell to Cell power dissipations

P_{in} = 412 W (nominal power)

P_{in} = 336 W (with beam)

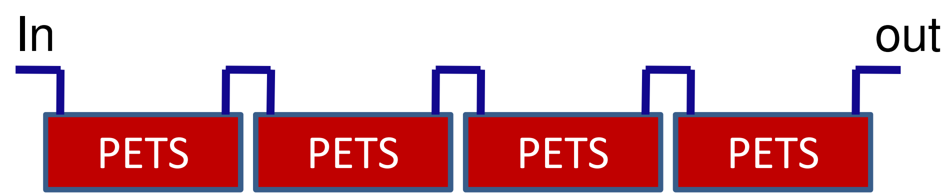
For nominal

ΔT_{AS} = 6.8 K

ΔT_{Water} = 5 K

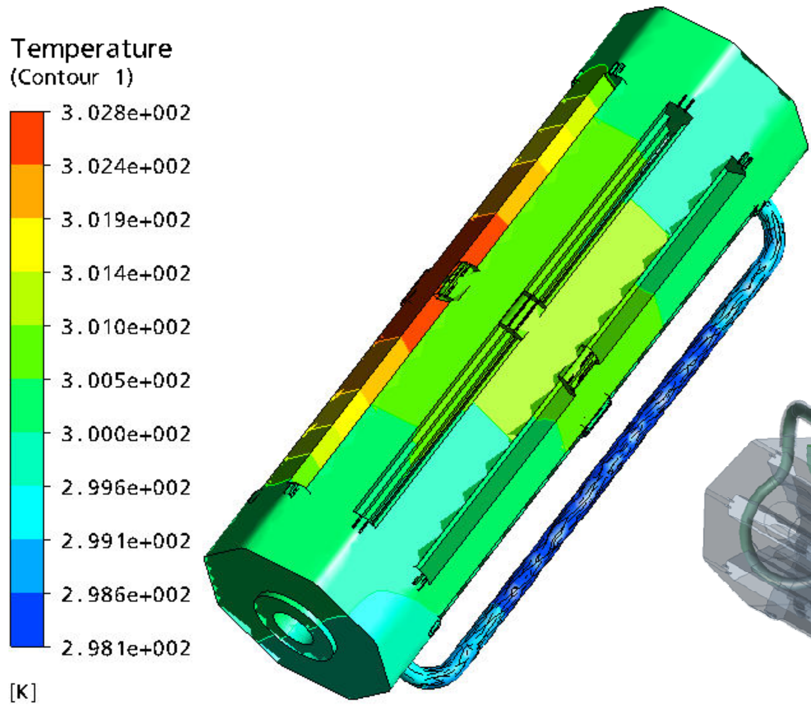
Total ΔT_{Water} = 10 K

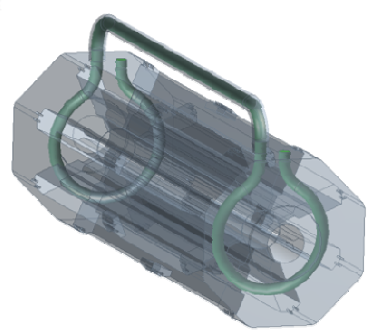
Module cooling baseline - PETS



1st PETS: Tin = 25C, flow 39 l/hr

Baseline of the routing





Octant to octant power dissipations

P_{in} = 39 W (safety is 2 for beam loss)

For a module (4 PETS)

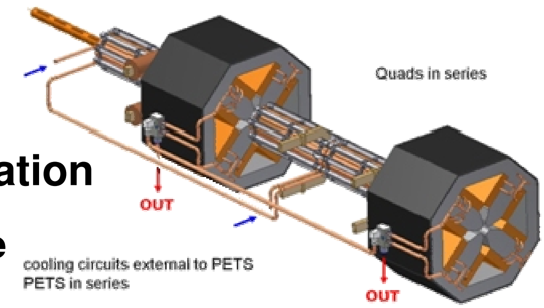
ΔT_{Water} = 3.3 K

Module cooling challenges

Cooling design that sustains alignment

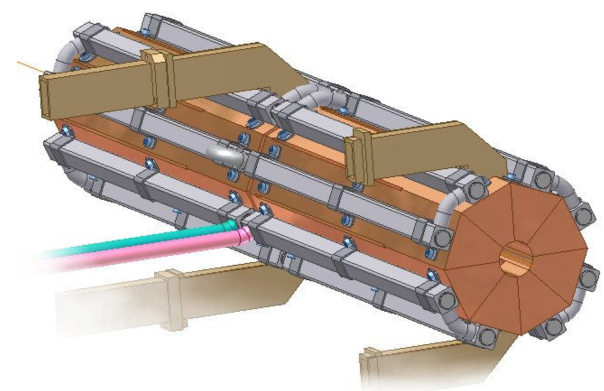
Thermal stability — Accelerator's performance is strongly coupled with temperature

Thermal effects:
- **Predictable: operational temperature, longitudinal elongation, transverse elongation**
- **Unpredictable: water temperature instability, RF power variation**



Big overall dissipation

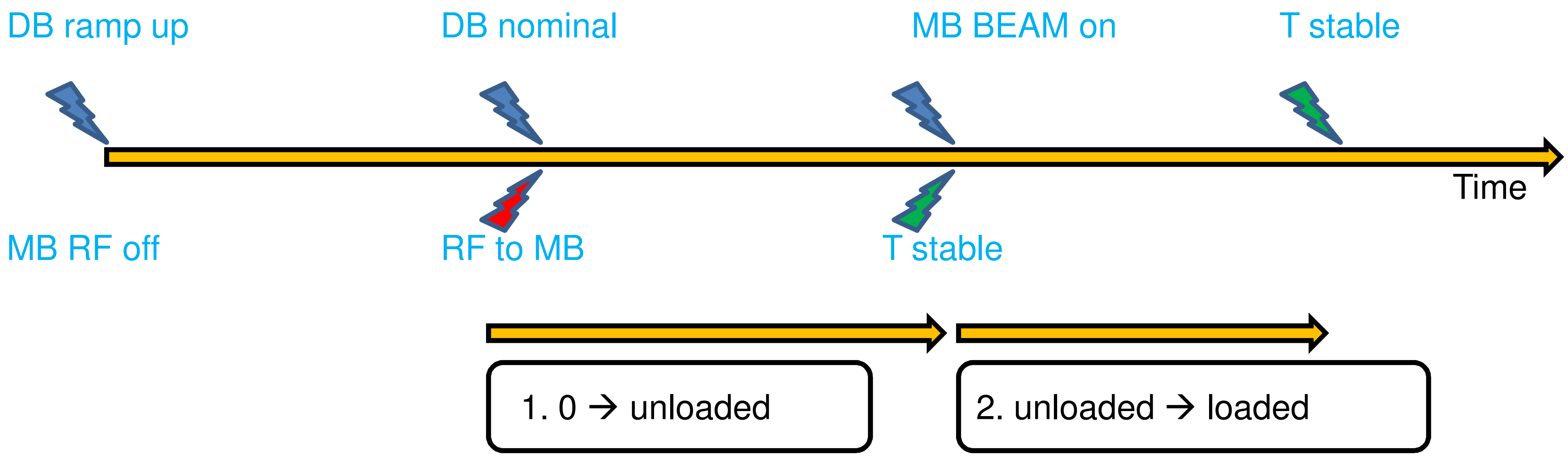
System Integration



Towards thermo-mechanical model

Overview

- Our current approach
  - Currently preliminary work is done with ANSYS
    - Incrementally from smaller to larger (some technical details there)
    - Selection of software is not written on stone… (Multi-physics simulations)
  - Extension of existing model via including new subsystems and boundary conditions
- Time constants between stable thermal conditions are being simulated
- Operation ramp up sequence of the accelerator can be looked also from the thermal dissipation point of view. At this stage the simplest approach is to use a scenario shown below

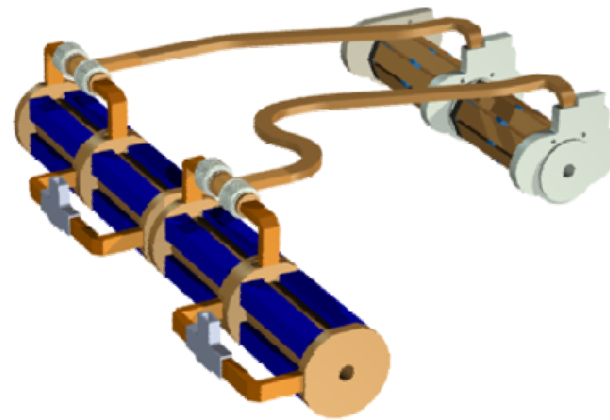


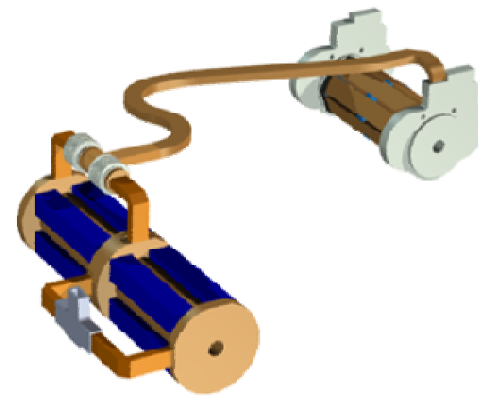
First configurations

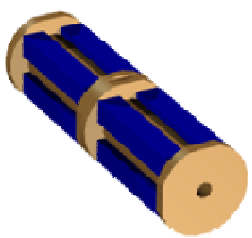
Process:

A. Define thermal behavior of a component / subsystem
B. Derive structural behavior
C. Run other simulations needed

D. Add a new component or system to model and start from A







1. Unloaded
1. Loaded
1. 0 → Unloaded
1. Unloaded → Loaded

2. Nominal

3. Unloaded

Configurations
0. Boundary conditions
1. Unloaded
1. Loaded
1. 0 → Unloaded
1. Unloaded → Loaded
2. Nominal
3. Unloaded

0. Boundary conditions

AS (specification)

Thermal dissipation

Cell-to-Cell thermal dissipations included

Cooling

Heat transfer coefficient: 3737 W/m^2/K,
Tin = 25 ℃, Tout = 35 ℃

Ambient temperature increases in steps through cooling ducts

Baseline routing

PETS (specification)

Thermal dissipation

Thermal dissipation included into PETS bars, beam loss falls to one bar

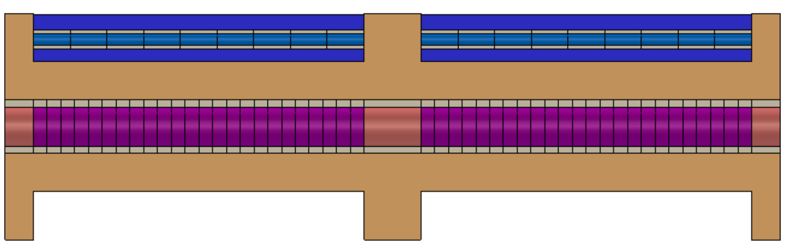
Cooling

Heat transfer coefficient: 1400 W/m^2/K,
Tin = 25 ℃, Tout = 25.8 ℃

Couplers are cooled

Ambient temperature is constant

Baseline routing

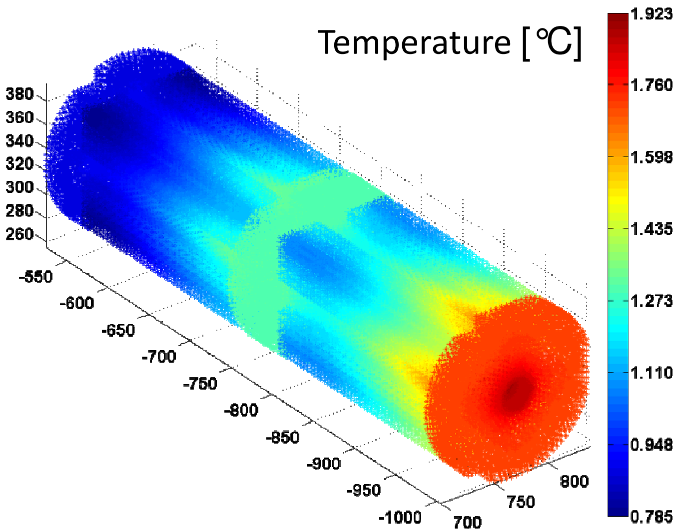


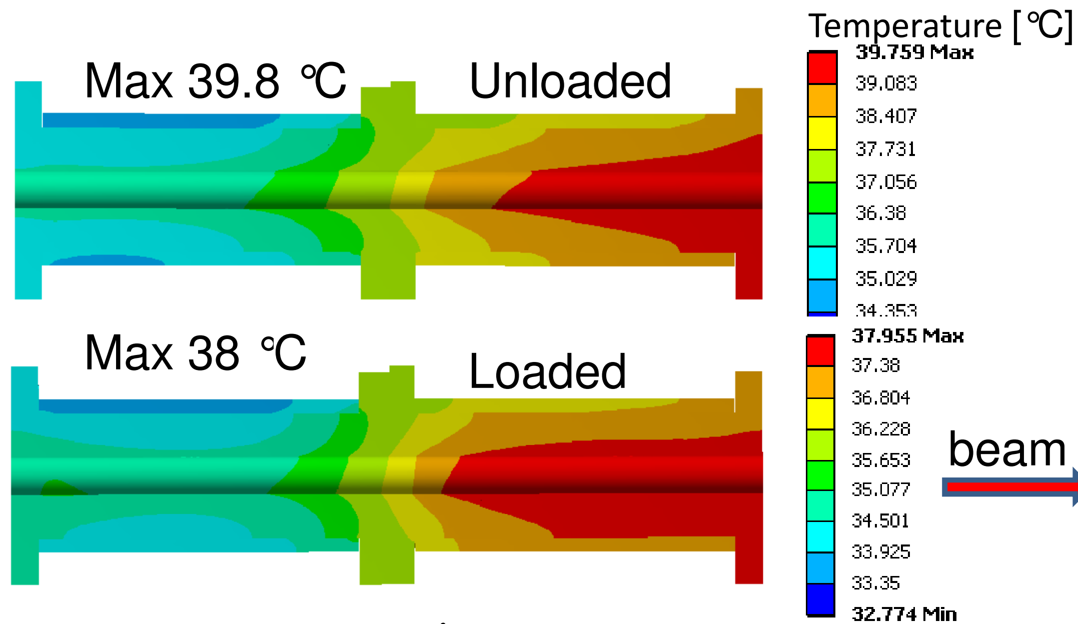
A super structure

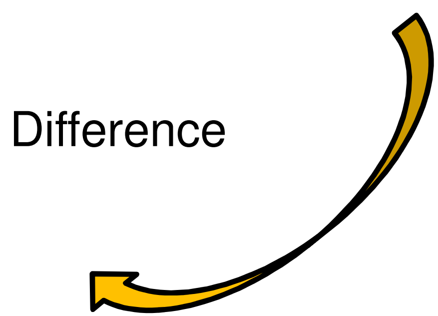
Configurations
0. Boundary conditions
1. Unloaded
1. Loaded
1. 0 → Unloaded
1. Unloaded → Loaded
2. Nominal
3. Unloaded

Nominal temperature distributions

- Accelerating structure nominal conditions (superstructure)
- AS cooling
  - 3737 W/m^2/K, 25 °C
- Input Power
  - Unloaded 412 W
  - Loaded 336 W





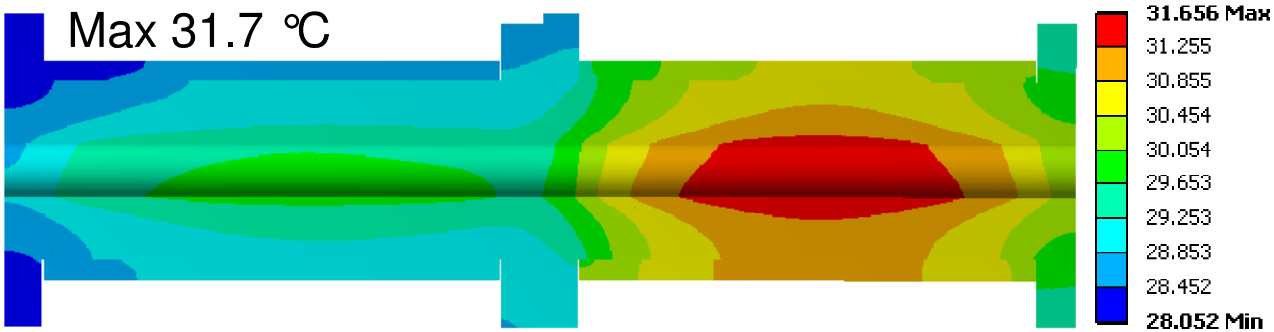


Configurations
0. Boundary conditions
1. Unloaded
1. Loaded
1. 0 → Unloaded
1. Unloaded → Loaded
2. Nominal
3. Unloaded

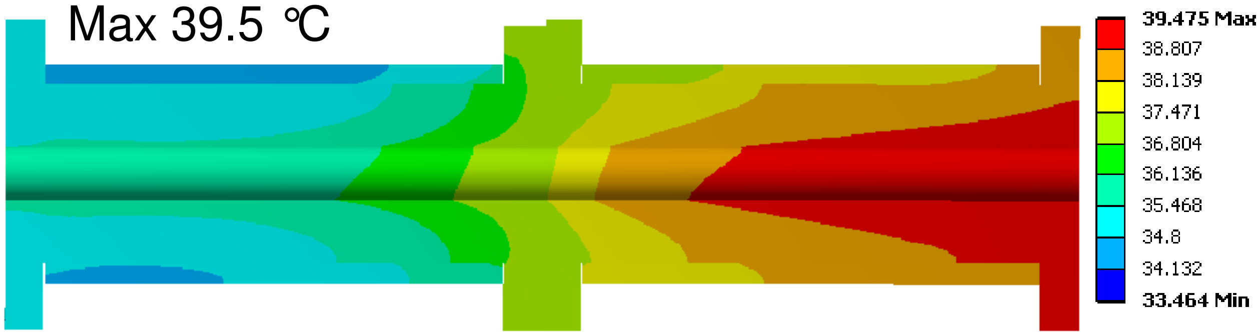
0 → Unloaded

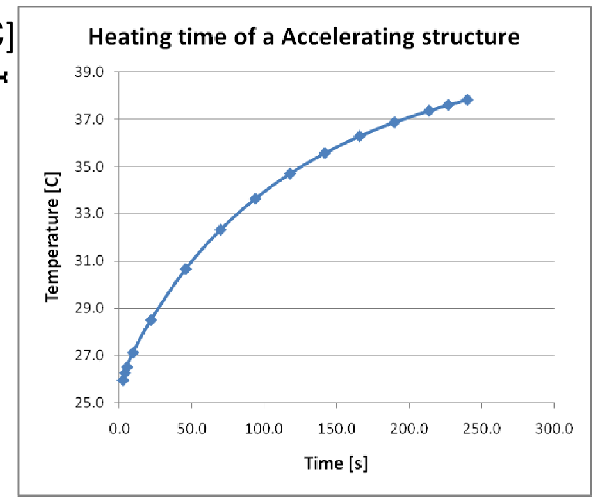
- Accelerating structure heating in unloaded condition
  - Initial temperature 25°C
- According to results ramp up time to stable condition is 8 minutes
- The model does not take into account conduction to support structures

After 60 seconds in unloaded



After 480 seconds in unloaded

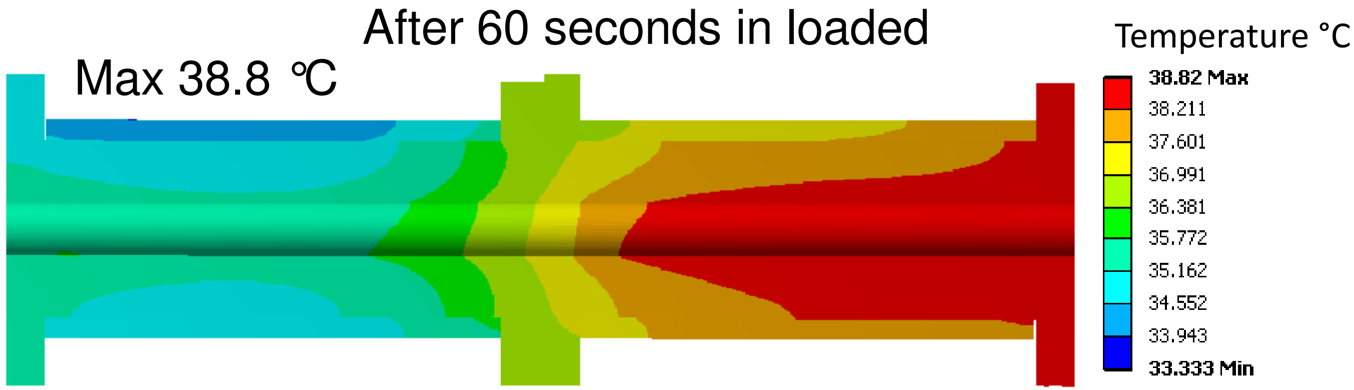


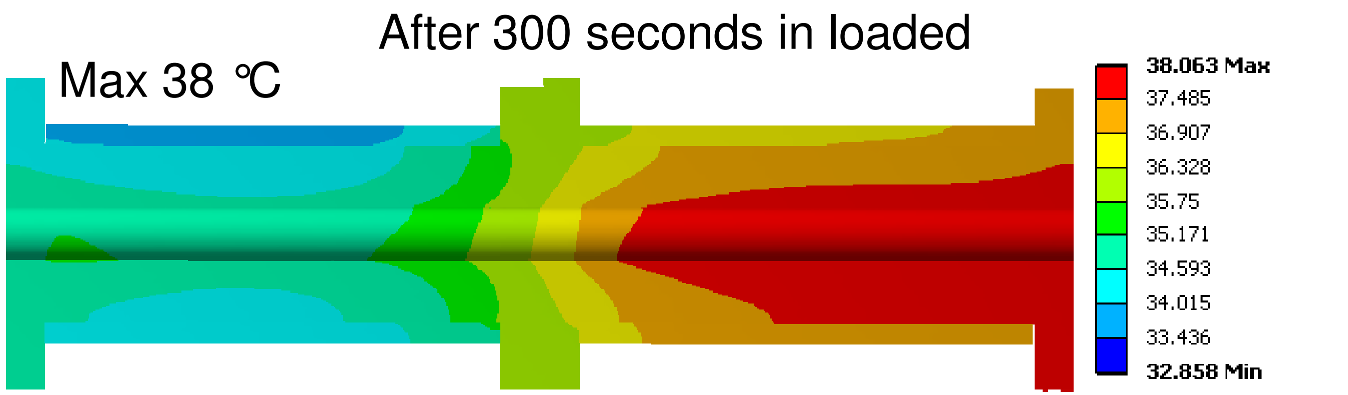


Configurations
0. Boundary conditions
1. Unloaded
1. Loaded
1. 0 → Unloaded
1. Unloaded → Loaded
2. Nominal
3. Unloaded

Unloaded → Loaded

- Accelerating structure heating in unloaded condition
  - Initial temperature : Unloaded steady state condition
- According to results stable condition is achieved in 5 minutes
- The model does not take into account conduction to support structures





Configurations
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1. Unloaded
1. Loaded
1. 0 → Unloaded
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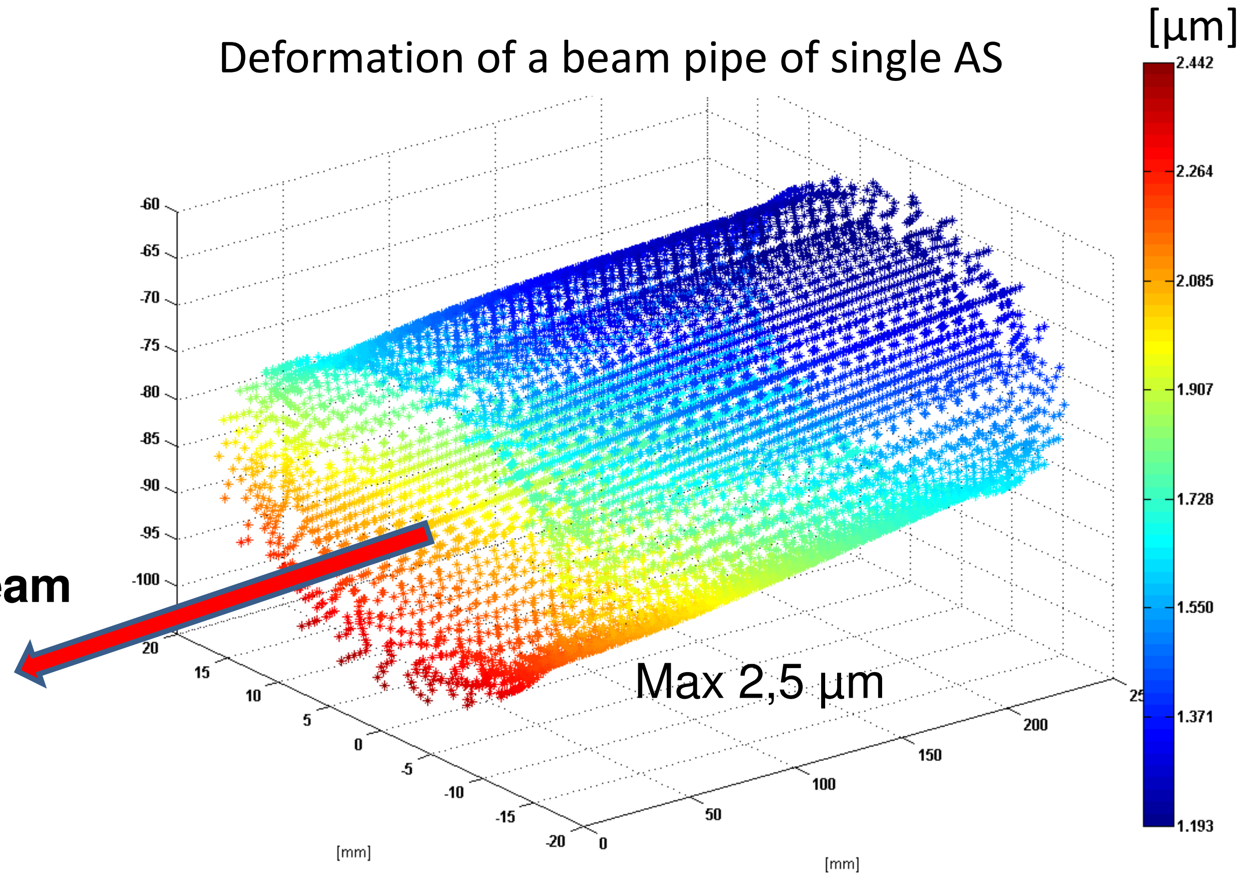
2. Nominal
3. Unloaded

Unloaded → Loaded



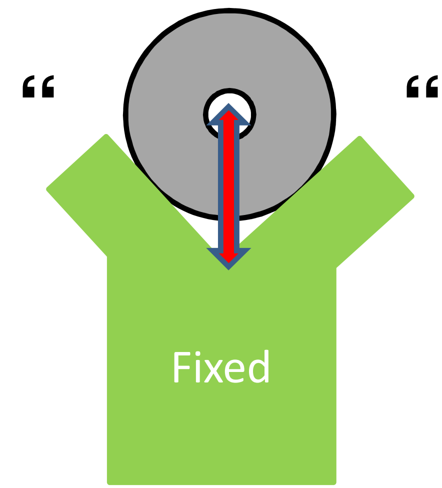


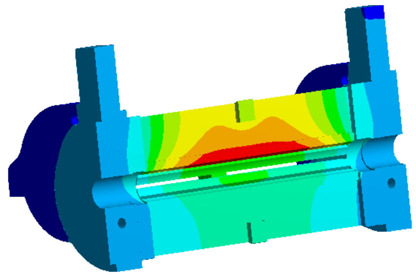
Illustration of transversal movement induced by the thermal expansion

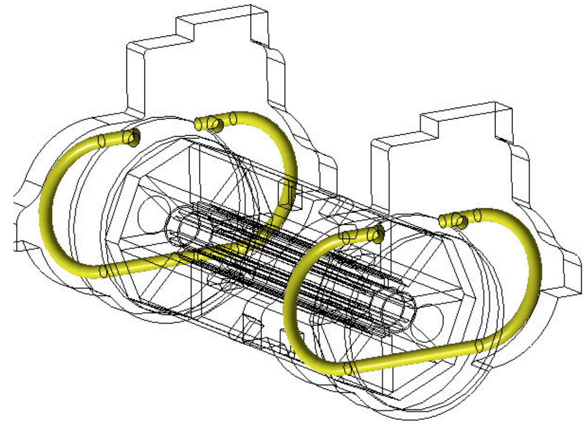
Simulation was done for a single accelerating structure

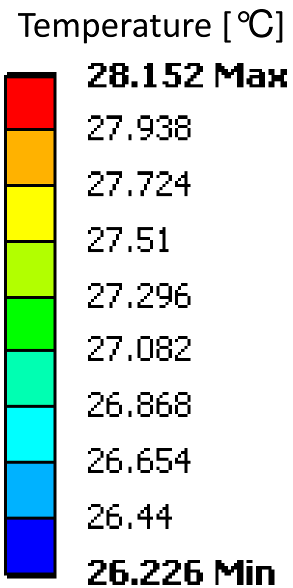
Configurations
0. Boundary conditions
1. Unloaded
1. Loaded
1. 0 → Unloaded
1. Unloaded → Loaded
2. Nominal
3. Unloaded

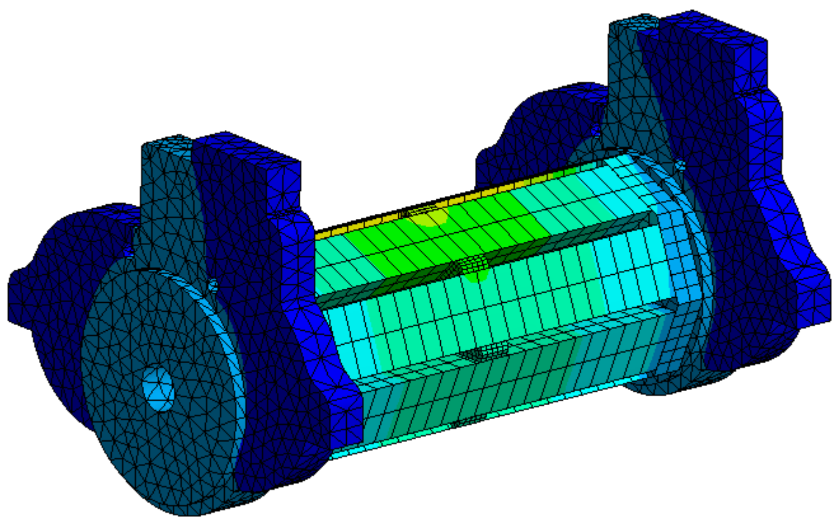
PETS

- PETS cooling
  - 1400 W/m^2/K, 25 °C
- Input 39 W
  - Beam loss 14 W
  - Surface currents 25 W









Configurations
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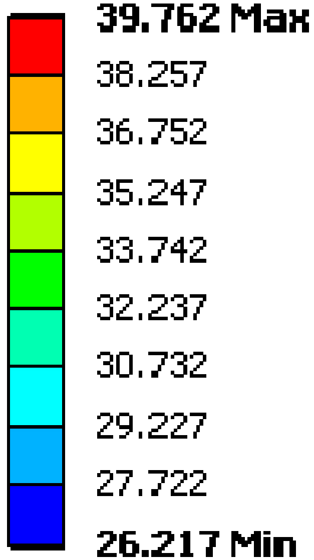
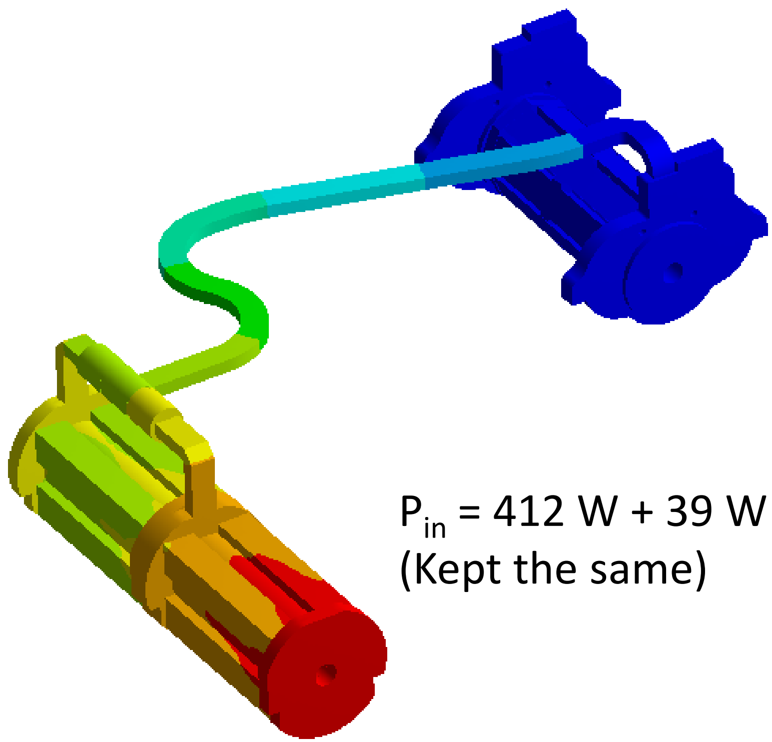
2. Nominal
3. Unloaded

N.B Cooling budget is up to 110 W, DB sector's integrated beam loss 0.5 %

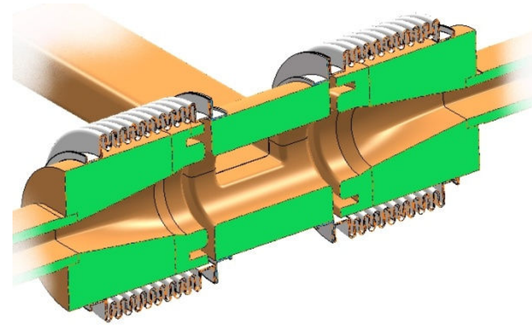
AS - WG - PETS

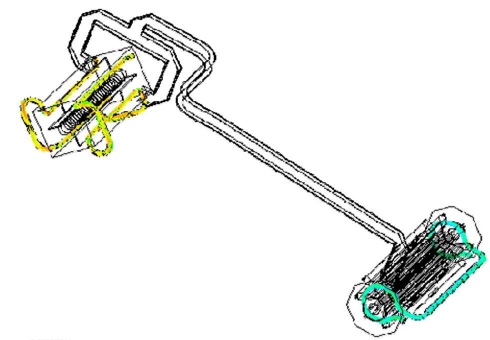
- Accelerating structure linked with a waveguide
  - Unloaded steady state condition
  - DB splitter with choke mode flanges included
  - Bellow modeled as a cylinder: wall thickness 0.1 mm
- Transversal dilatation is significant in thermal cycle

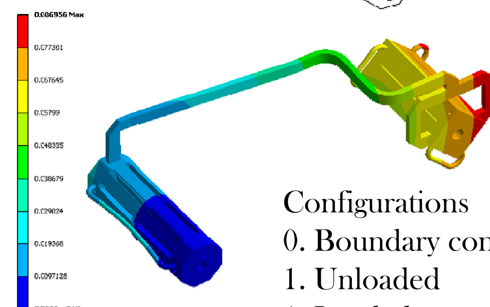




P_{in} = 412 W + 39 W
(Kept the same)







Configurations
0. Boundary conditions
1. Unloaded
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1. 0 → Unloaded
1. Unloaded → Loaded
2. Nominal
3. Unloaded

Conclusions

- Thermo-mechanical model improved hand in hand with improving technical design of systems
  - There is plenty of work in front of us…
  - Good practices to keep simulation simplification and thus solver time low is essential
- Thermal stability for a single super structure
  - From cold state to unloaded: 8 minutes
  - From unloaded state to loaded: 5 minutes
- Previous work
  - Definition of cooling parameters and behavior of single structure's behavior between operation modes
- Future work
  - Iterate boundary conditions in order to simplify FE-model
  - Extension of the model to structural simulations
  - Induced effect from coupling of beams, dilatations & forces
  - Operation modes' relation to RF-structure movement
- Your contribution is very welcome!

Thank you!