RF-Thermo-Structural study of CLIC Accelerating Structures

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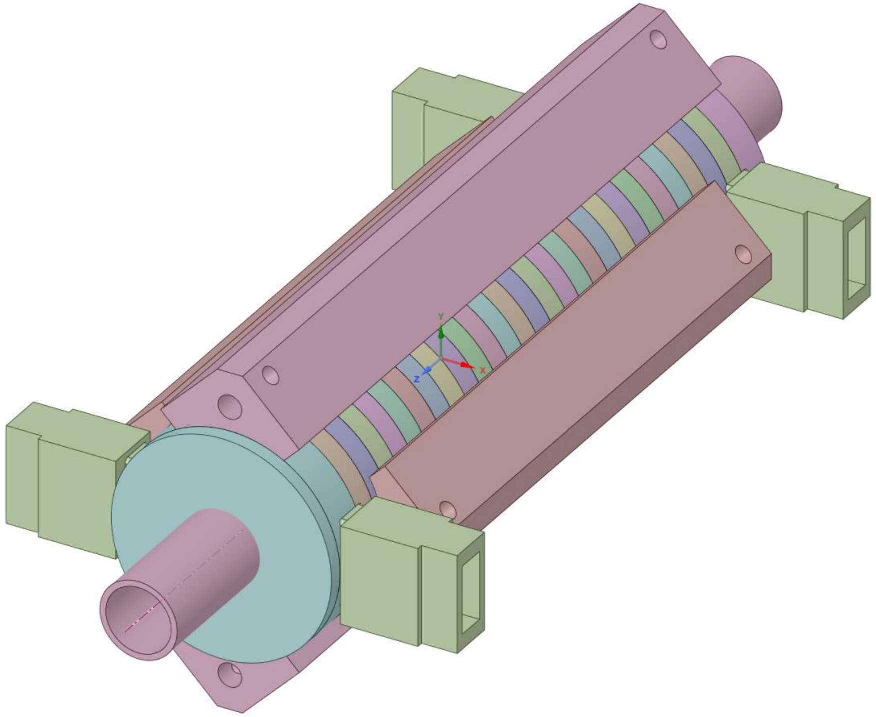
11.03.2020

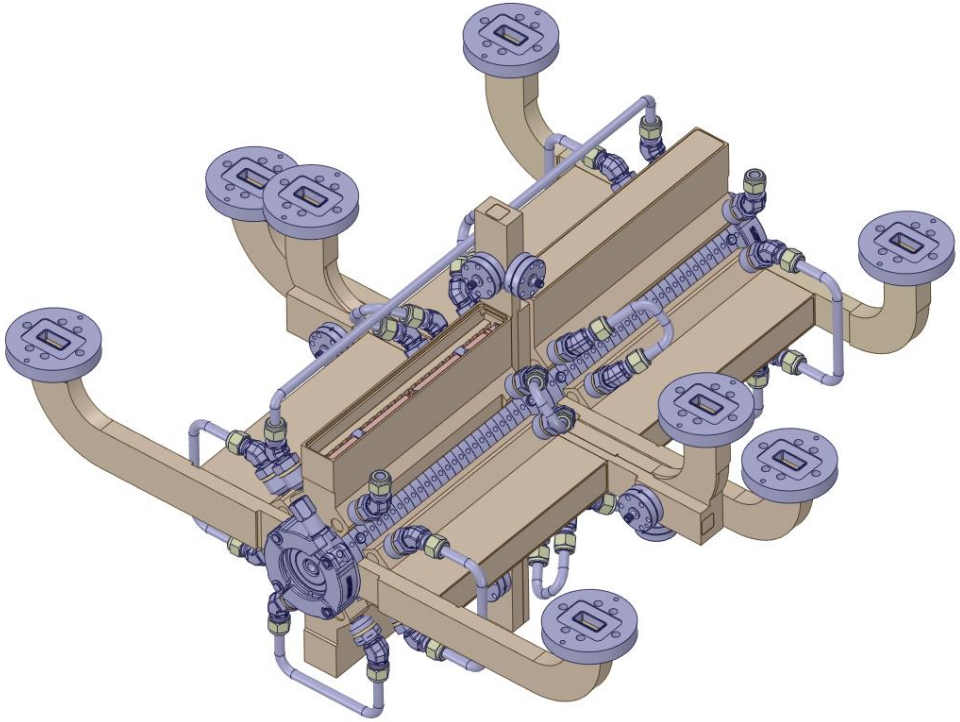
Structures of Interest

- Damped traveling wave accelerating structure using 26 cells and 2 matching cells
- Bending radius: 0.5mm

TD26R05CC

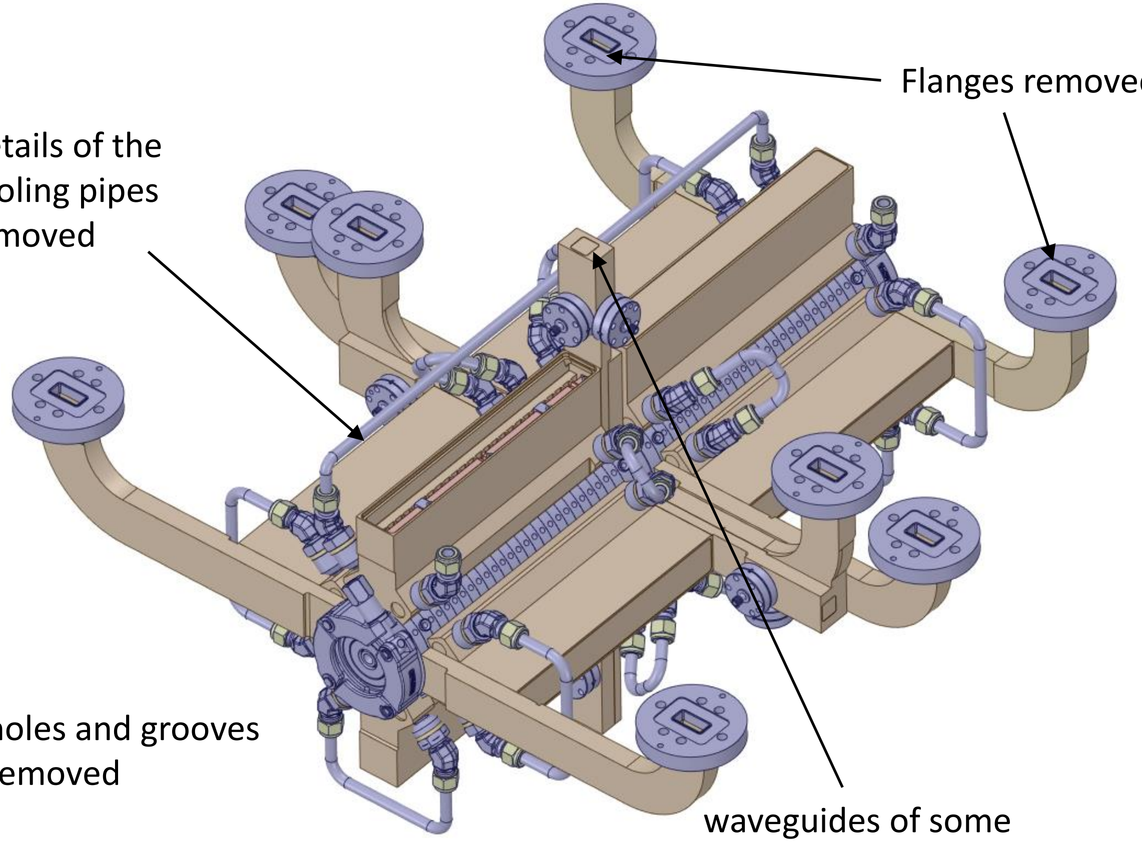


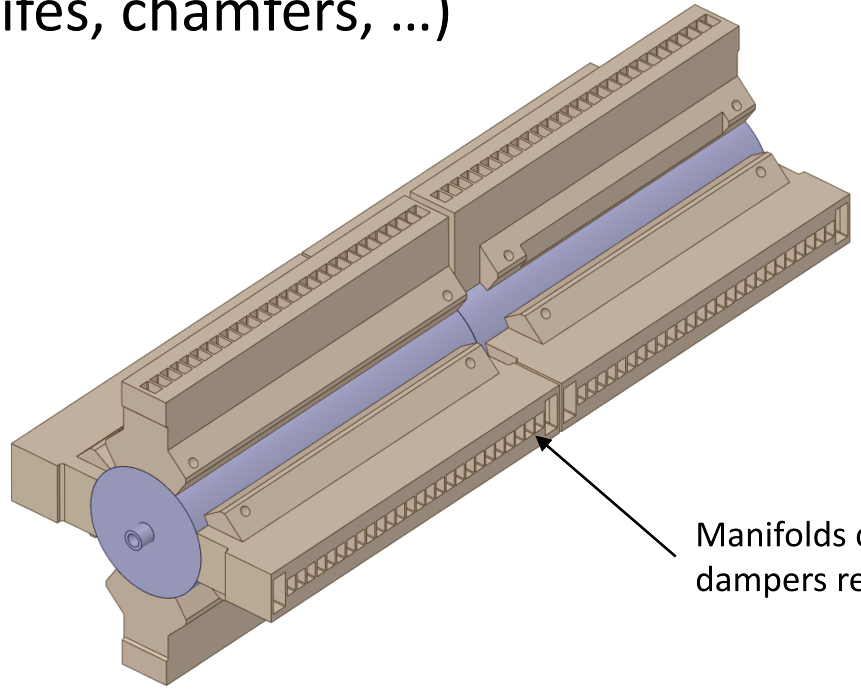
TD26R05SS



Model simplification

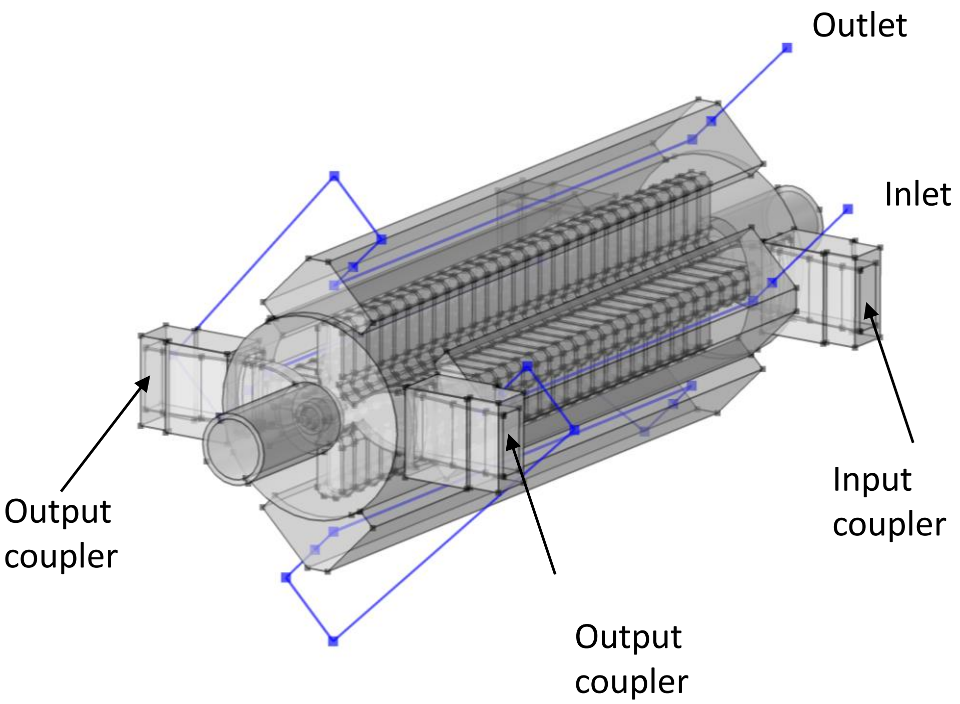
- Avoid healing
- Cooling circuit represented by polygon (1D)
- Clean contact between parts (no rounding, knifes, chamfers, …)

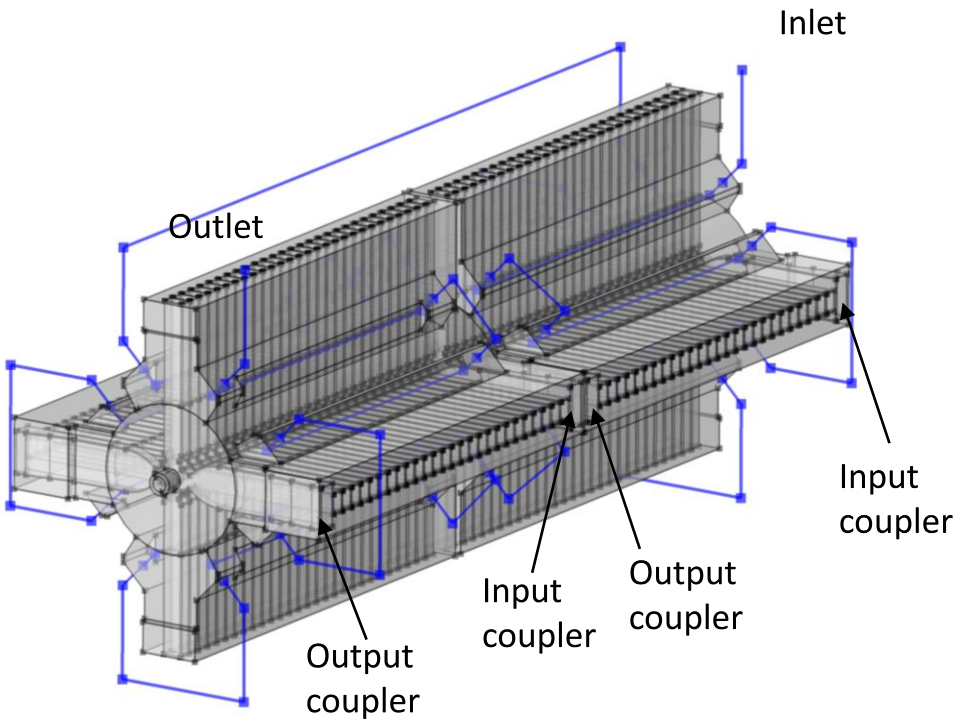




Cooling path

- 1D fluid flow model based on surface roughness, pipe diameter, inlet temperature, flow rate (no predefined convection heat transfer coefficient)
- Self-consistent with heat transfer in solid
- Single circuits for TD26R05CC and TD26R05SS (default):

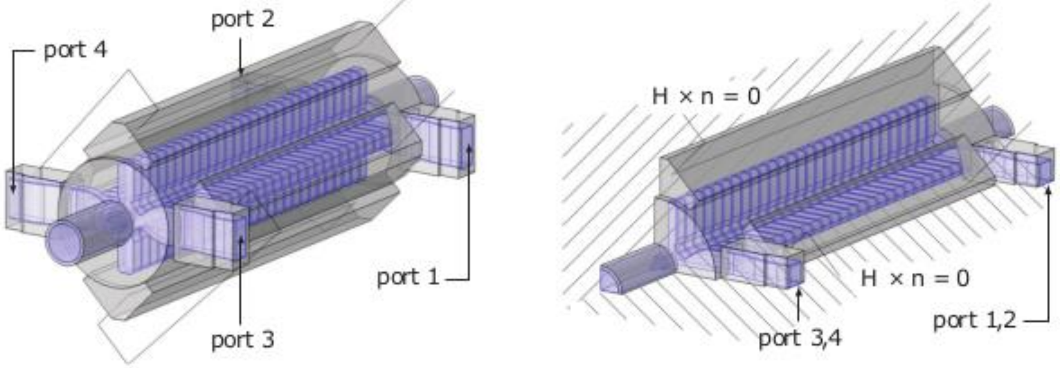




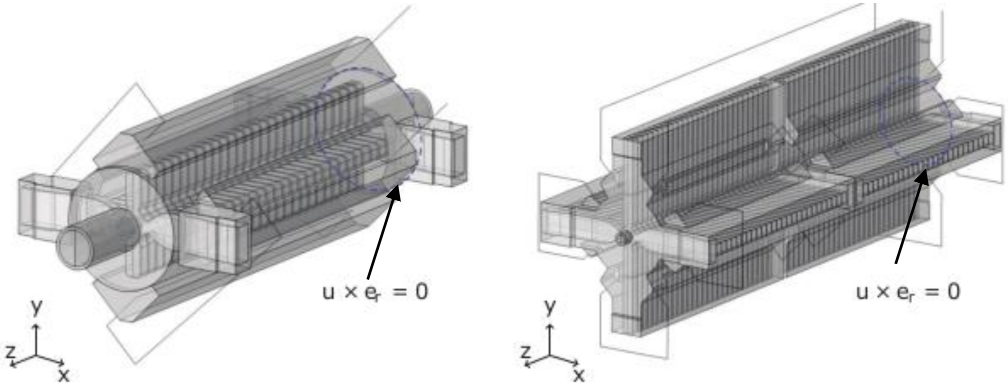
XB2 Installation

Symmetry

- If no symmetric cooling paths, thermal deformations break the symmetry
- Scattering Parameters calculated as for symmetric structure (combine ports)

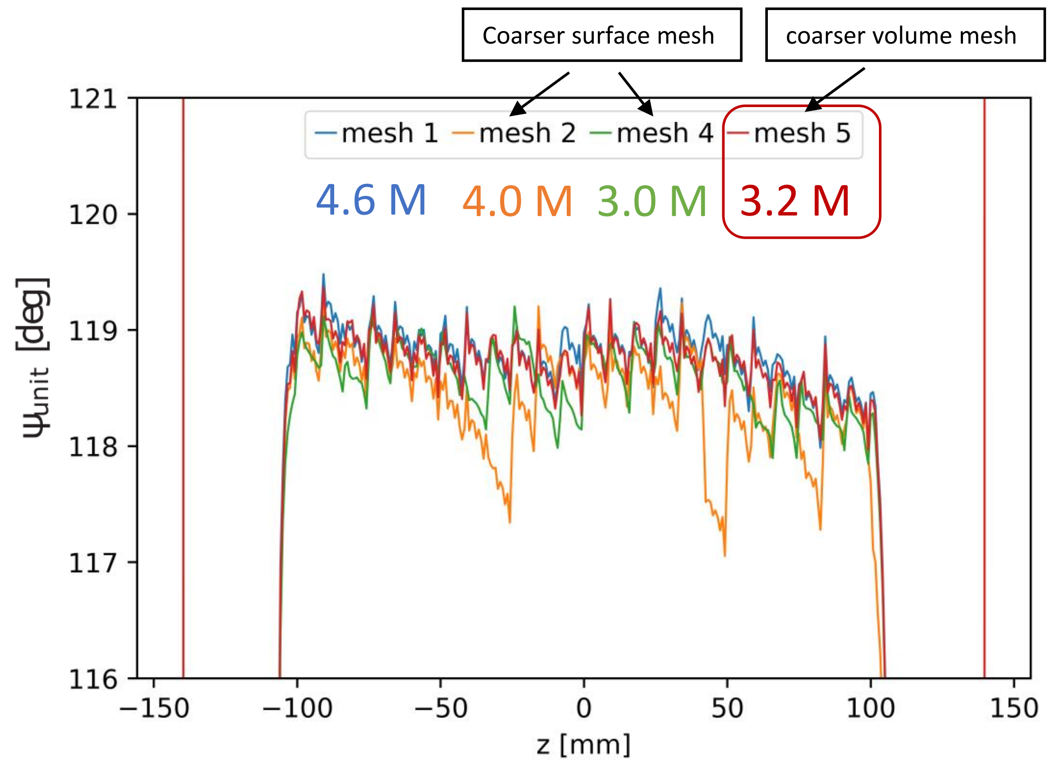


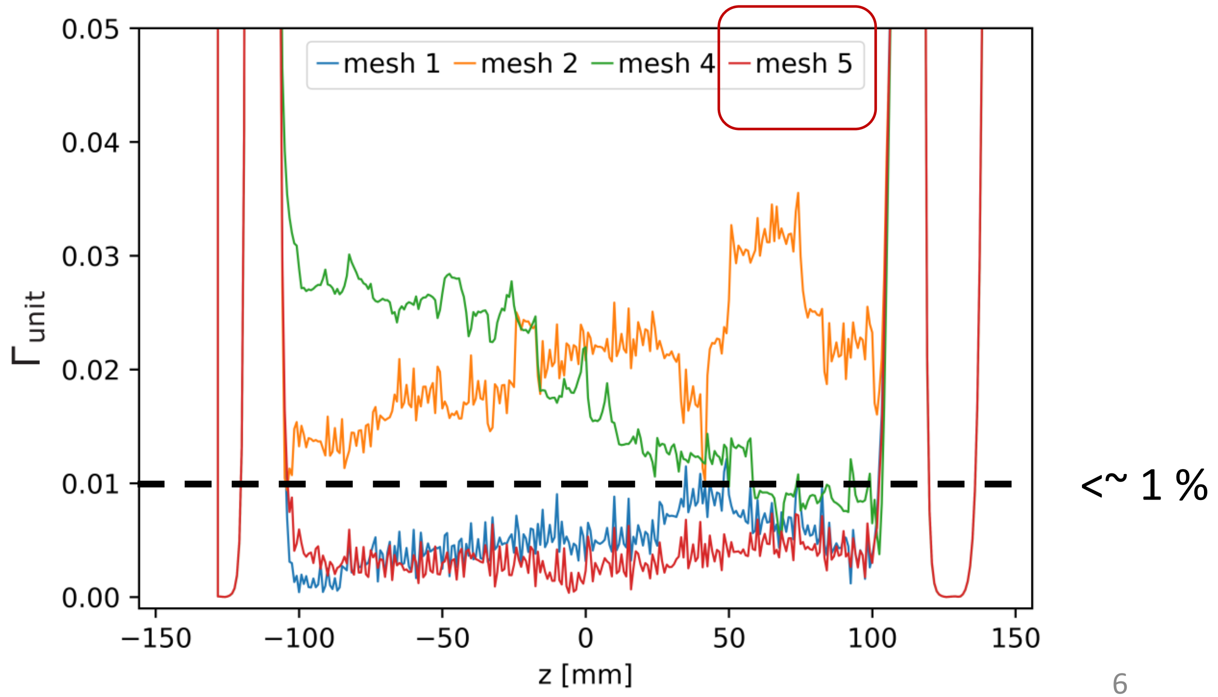
- Structure is fixed by allowing radial displacements at dashed edges



Mesh

- Convergence criteria: Kroll Parameters (phase advance per cell, Internal reflections)
- Manual mesh adaption (partitioning, refinements around beam line/ cavity surface)
- Example for TD26R05CC:

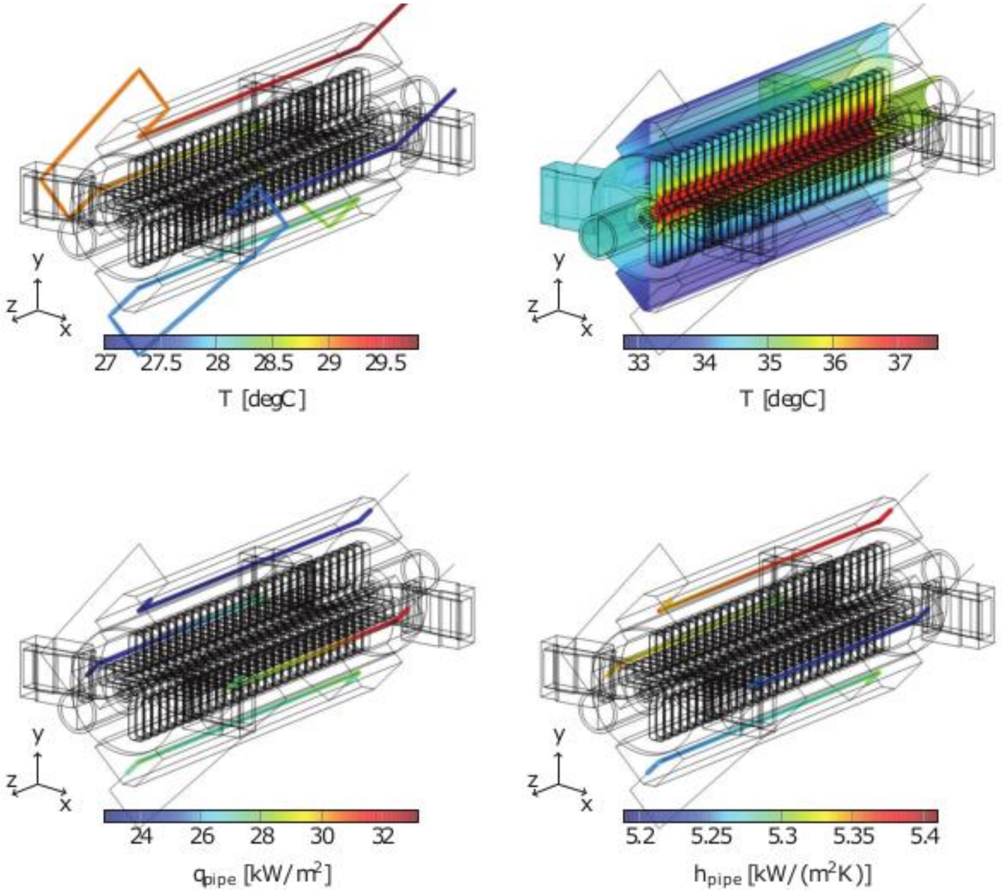




Heat Transfer and Pipe Flow

- Heat concentration around irises despite of large thermal conductivity
- Resulting heat transfer coefficient h_{pipe} verified by analytical calculations

TD26R05CC: 1kW input RF power, **3l/min** water flow rate, **5W/(m²K)** air convective heat transfer coefficient, T_{amb} = **28degC**, T_{inlet} = **27degC**



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- Delta T of 2 K between the structures of TD26R05SS

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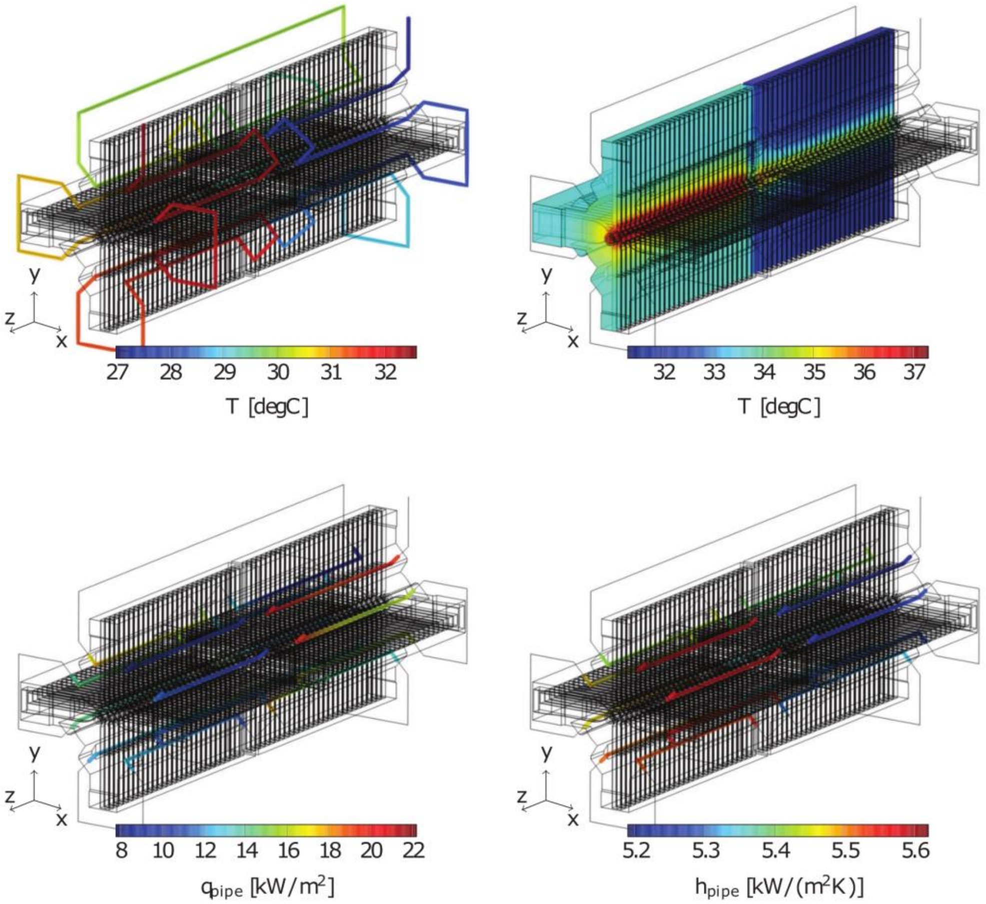

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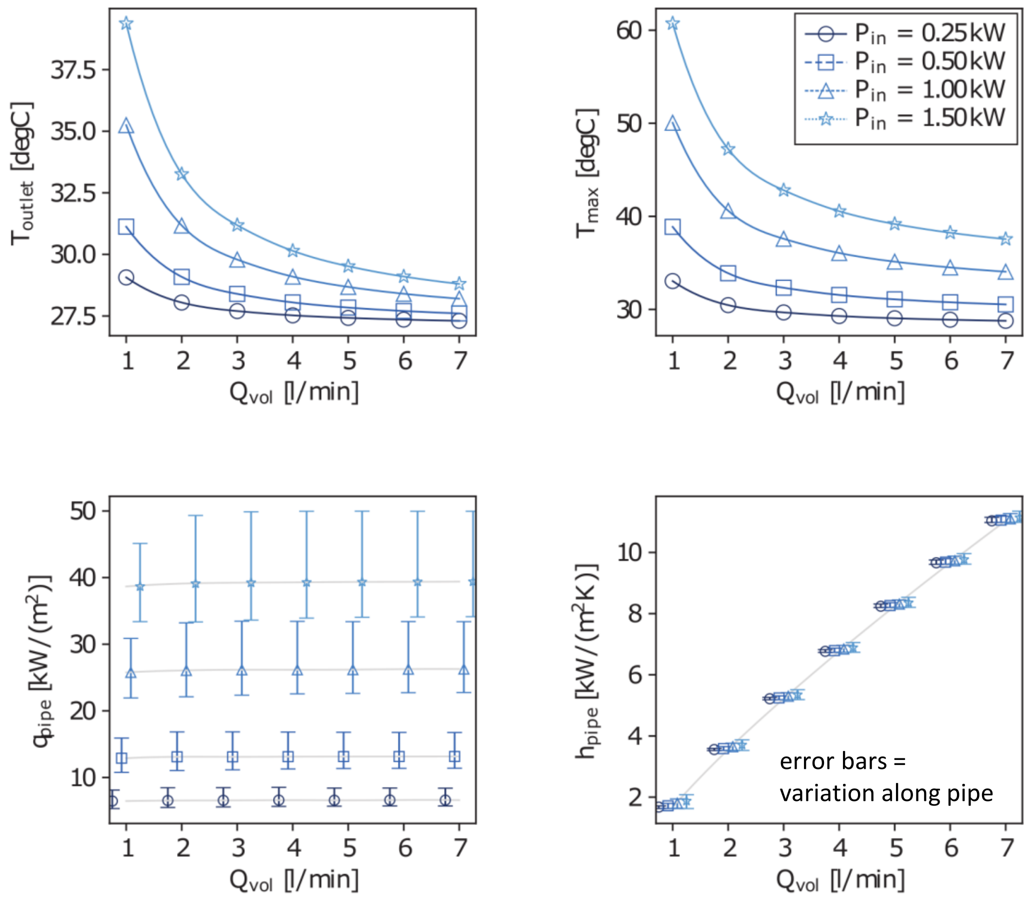

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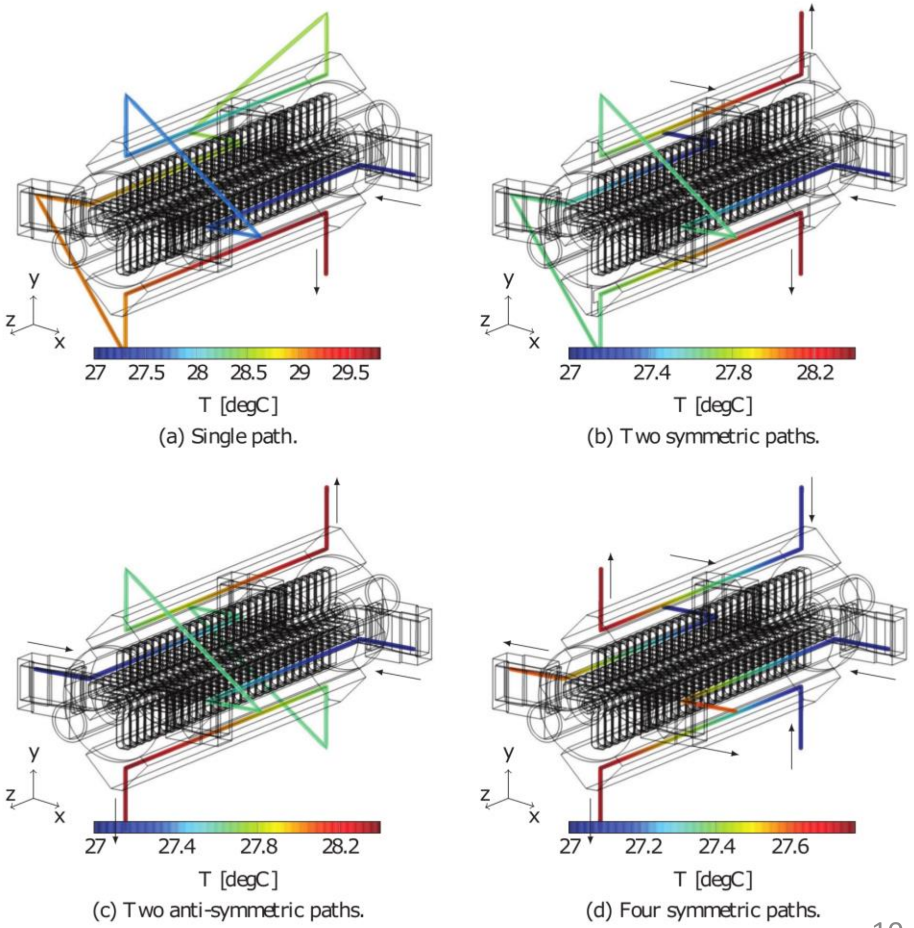

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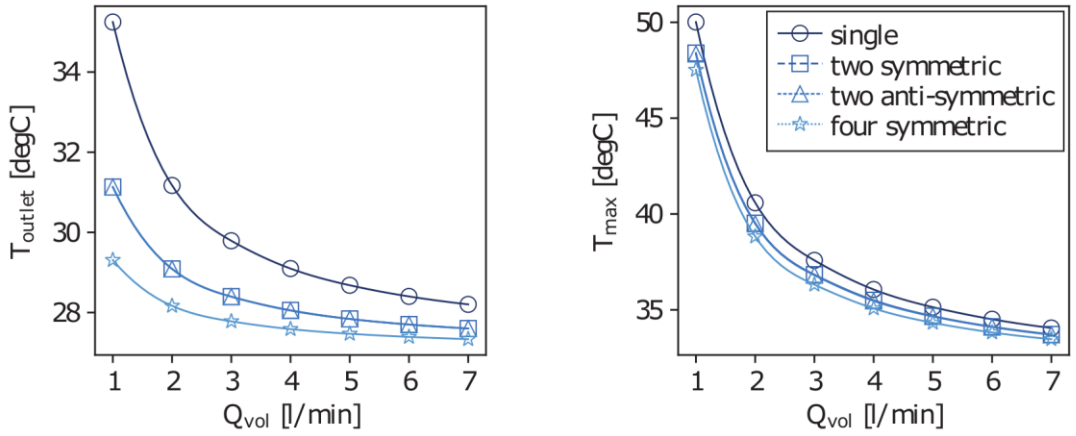

Heat Transfer and Pipe Flow

- Heat concentration around irises despite of large thermal conductivity
- Resulting heat transfer coefficient h_{pipe} verified by analytical calculations
- Delta T of 2 K between the structures of TD26R05SS
- Saturation of cooling Q_{vol} > 3l/min
- Changes of cooling path has marginal impact on temperature distribution
- Significant impact by surface roughness of the cooling pipes

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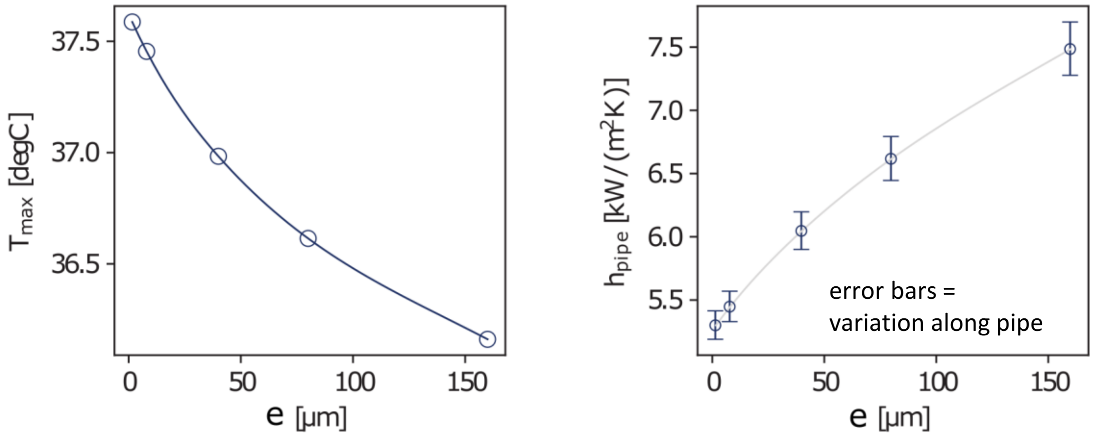

e = 1.5 um corresponds to **drawn tubes** and was considered so far to be on the conservative side

Structural Deformation

- Thermal expansion using T_{amb} as reference temperature
- Single cooling circuit result in slight

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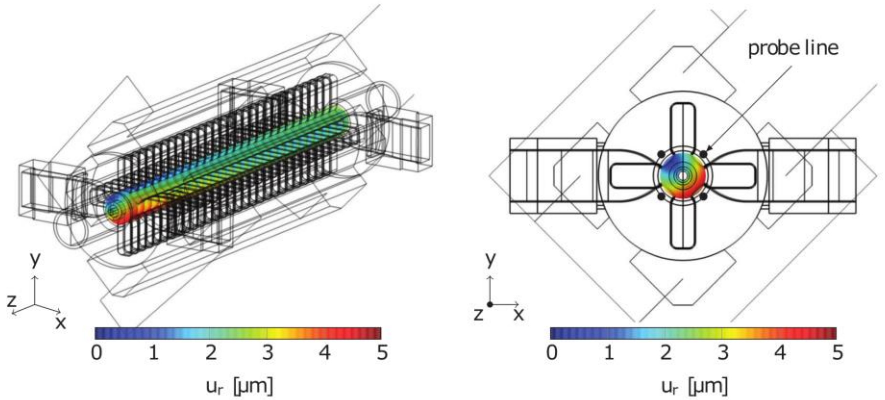
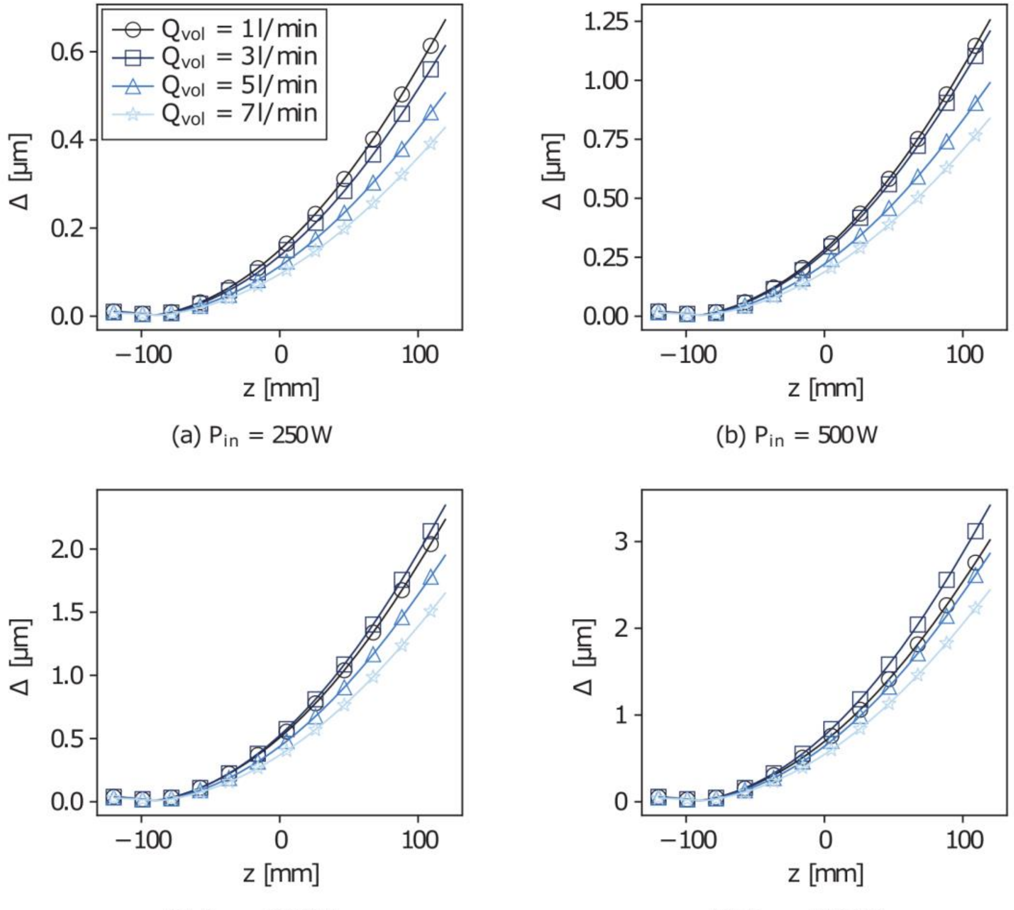


Transverse displacement of center axis as sum of x and y components of structural displacement over four probe lines (black dots)

Structural Deformation

- Thermal expansion using T_{amb} as reference temperature
- Single cooling circuit may result in few micron transverse center displacement

TD26R05CC: var input RF power, **var** water flow rate, **5W/(m²K)** air convective heat transfer coefficient, T_{amb} = **28degC**, T_{inlet} = **27degC**



(a) P_{in} = 250W (b) P_{in} = 500W (c) P_{in} = 1000W (d) P_{in} = 1500W

Structural Deformation

- Thermal expansion using T_{amb} as reference temperature
- Single cooling circuit may result in few micron transverse center displacement
- Symmetry of displacements follows from symmetry of cooling paths

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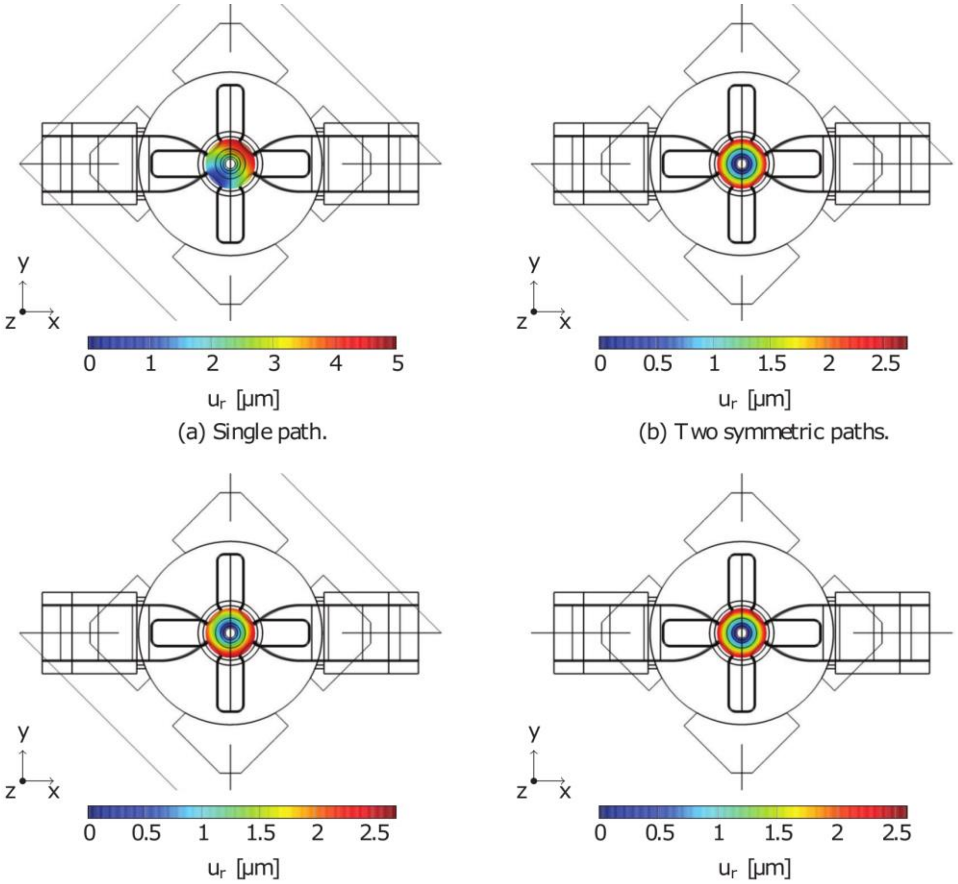

(a) Single path.
(b) Two symmetric paths.
(c) Two anti-symmetric paths.
(d) Four symmetric paths.

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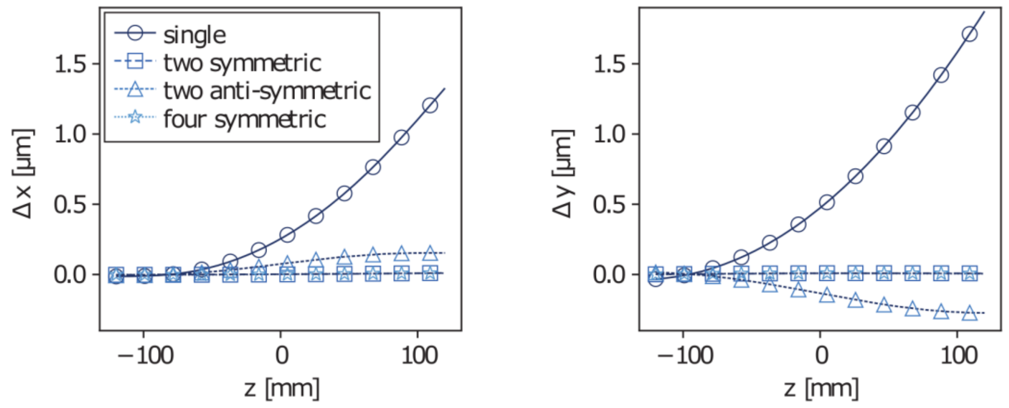

"two symmetric paths" and "four symmetric paths" allow to consider only a quarter for the coupled problem

Structural Deformation

- Thermal expansion using T_{amb} as reference temperature
- Single cooling circuit may result in few micron transverse center displacement
- Symmetry of displacements follows from symmetry of cooling paths
- Mesh displacement of the vacuum part according to the surrounding structure deformation except for beam line

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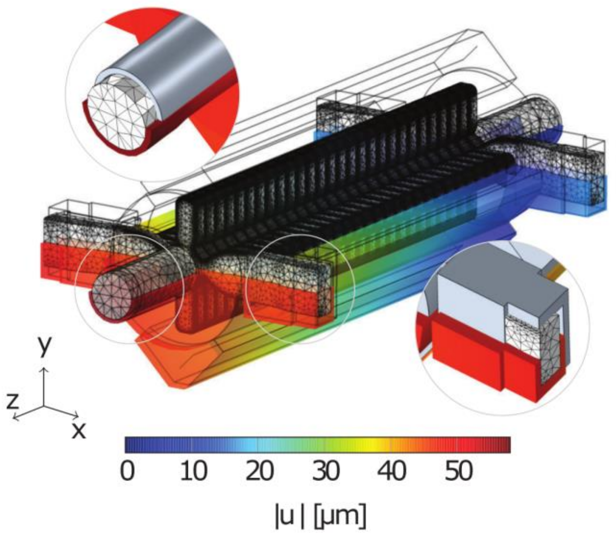
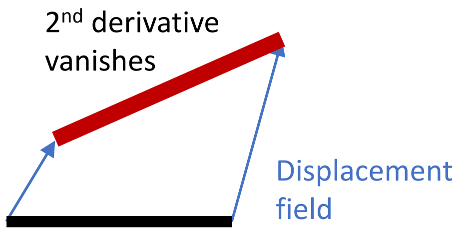


Displacement of port surface by solving Laplace-like equation taking into account the surrounding structural deformation as Dirichlet boundary condition



Studies on Perturbed Structures

- Phase advance Ψ_{unit} and internal reflections Γ_{unit} generally increases when accounting thermal conditions

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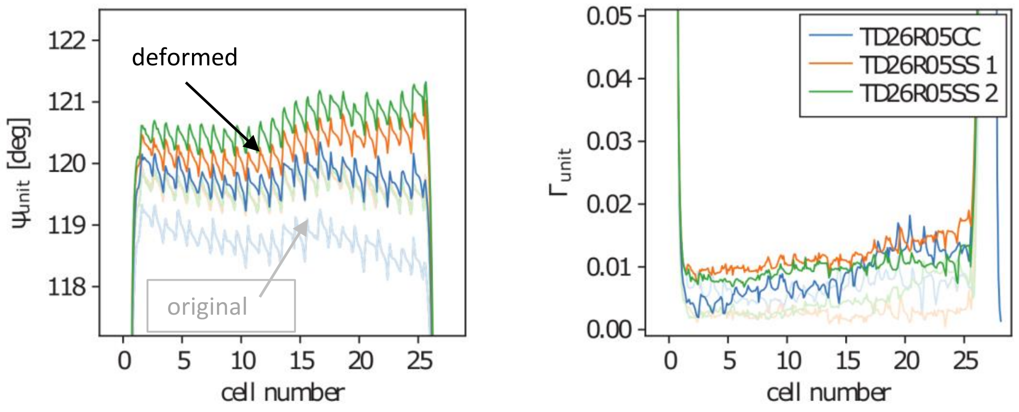
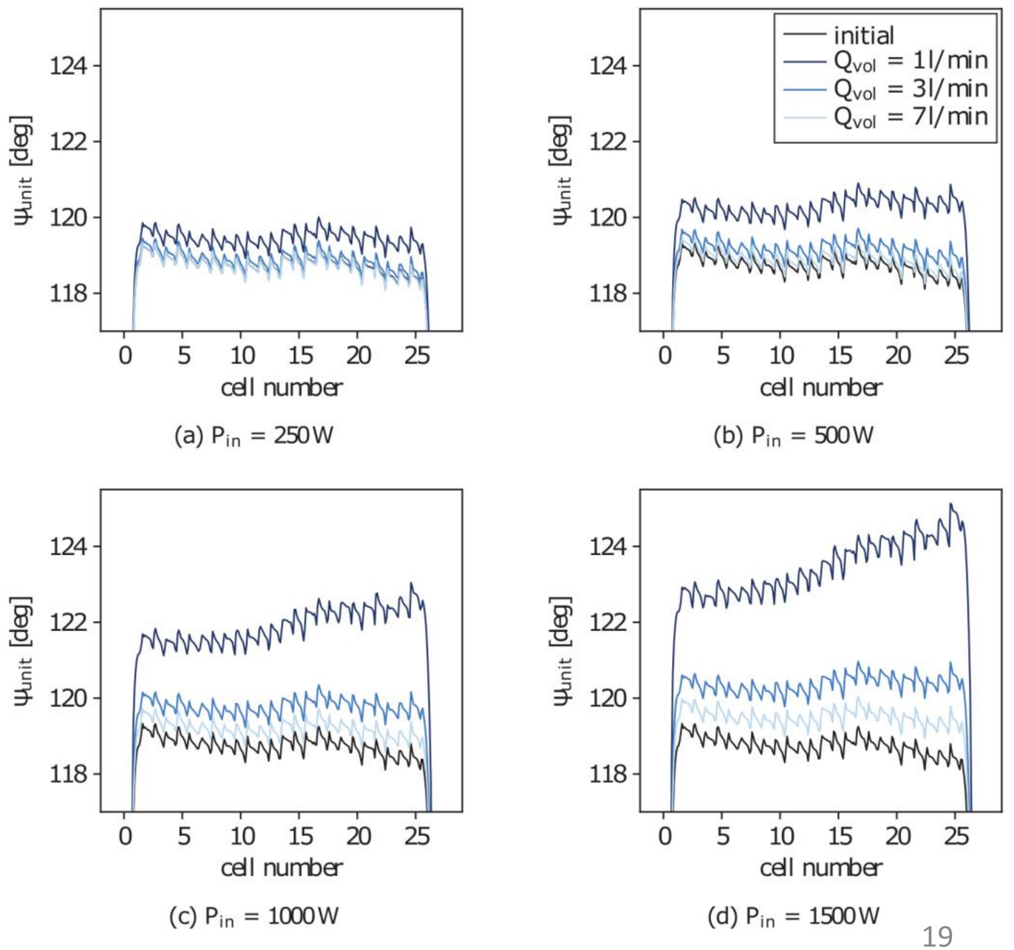


Cell-to-cell phase advance of TD26R05CC by design around 119 deg due to shorter and rounded waveguides

Studies on Perturbed Structures

- Phase advance Ψ_{unit} and internal reflections Γ_{unit} generally increases when accounting thermal conditions
- Flow rate ≥ 3l/min required to reduce impact of RF heating on Ψ_{unit} and Γ_{unit}

TD26R05CC: var input RF power, **var** water flow rate, **5W/(m²K)** air convective heat transfer coefficient, T_{amb} = **28degC**, T_{inlet} = **27degC**



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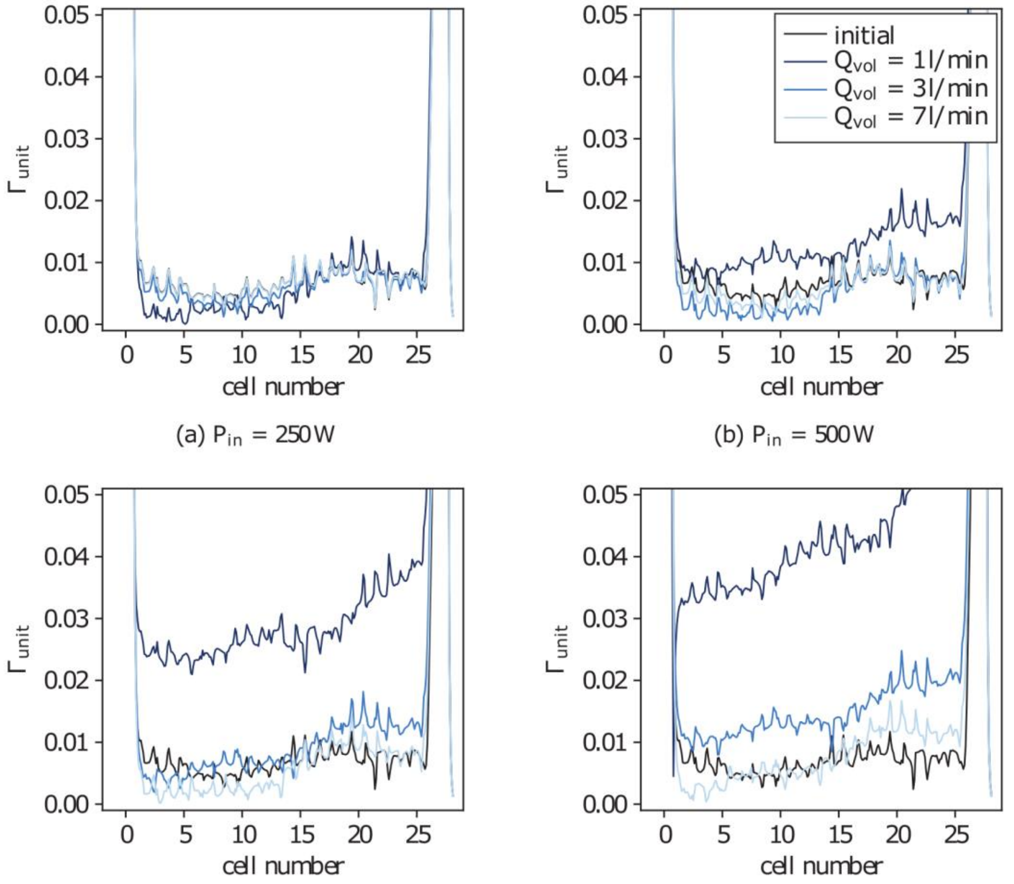

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- Qualitative same RF results for different cooling paths

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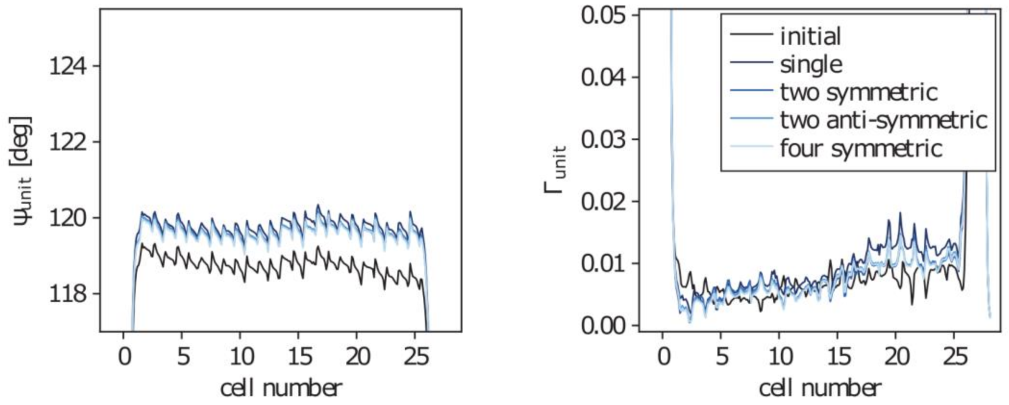
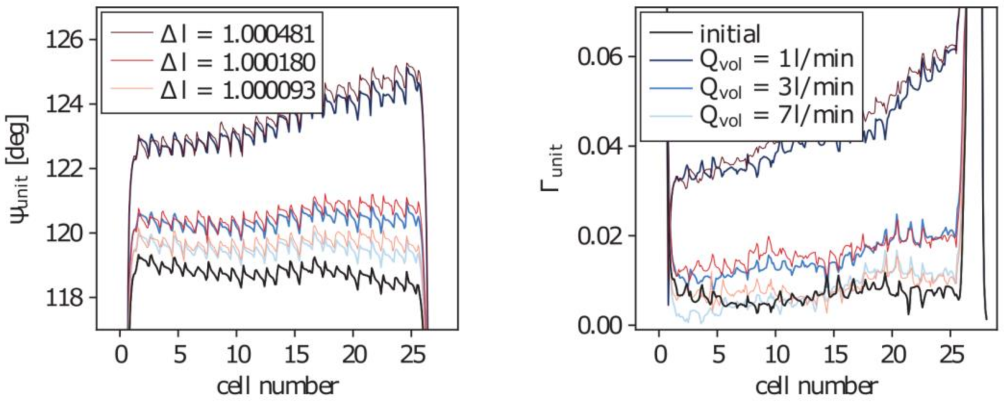


Studies on Perturbed Structures

- Phase advance Ψ_{unit} and internal reflections Γ_{unit} generally increases when accounting thermal conditions
- Flow rate ≥ 3l/min required to reduce impact of RF heating on Ψ_{unit} and Γ_{unit}
- Similar results for different cooling paths (marginal impact)
- Qualitative same RF results for scaled geometry

TD26R05CC: 1.5kW input RF power, **var** water flow rate, **5W/(m^{2}K)** air convective heat transfer coefficient, T_{amb} = **28degC**, T_{inlet} = **27degC**



Relative length variation Δl is based on the variation of the cavity length (longitudinal change)

Studies on Perturbed Structures

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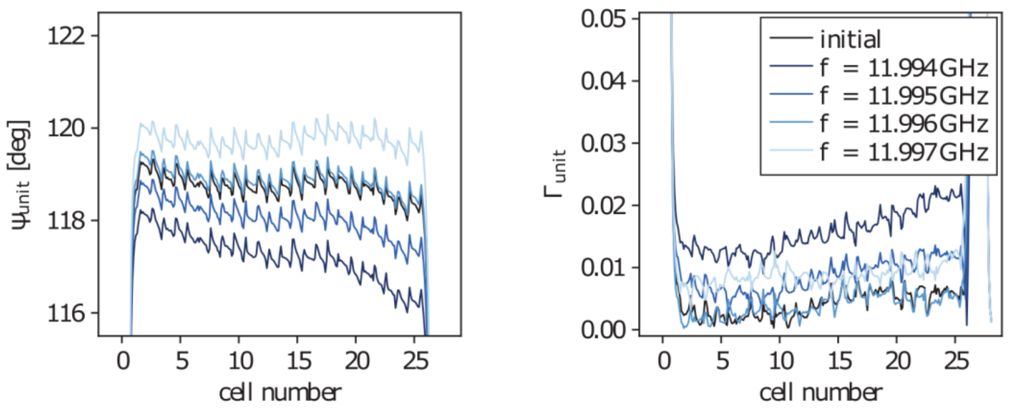
- Flow rate ≥ 3l/min required to reduce impact of RF heating on Ψ_{unit} and Γ_{unit}
- Similar results for different cooling paths (marginal impact)
- Qualitative same RF results for scaled geometry
- Frequency tuned by inlet temperature without compromising RF profiles

TD26R05CC: 1kW input RF power, **3l/min** water flow rate, **5W/(m²K)** air convective heat transfer coefficient, T_{amb} = **28degC**, T_{inlet} = **10degC**



Profiles of cell-to-cell phase and internal reflection **completely restored** at a frequency 2 MHz higher than by design

Summary

- Heat concentration around irises despite of large thermal conductivity
- Single cooling circuit can result in few micron transverse center displacement
- Flow rates of at least 3l/min should be considered to reduce enhancement of internal reflections and cell-to-cell phase advance
- RF behavior of deformed structure well described by a scaled model (no mesh deformation required)
- Frequency can be tuned by inlet temperature without compromising RF profiles