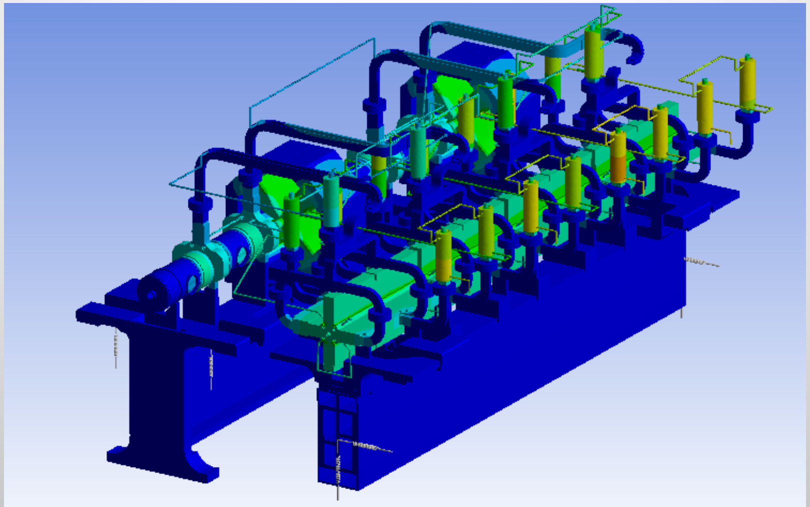
Thermal-Structural Finite Element Analysis of CLIC module T0#2

Antti Moilanen



1. Introduction
2. Simulation
3. Conclusions

1. Introduction

Thermo-mechanical analysis of CLIC module

Aim of the Finite Element Method (FEM) simulation is to study deformations caused by thermal gradients in CLIC module T0#2

Thermal gradients originate from several sources: RF structures produce heat, components are cooled by water and air flow, ambient temperature varies

The modelling is done using ANSYS 17.1 Workbench. The FEM simulation of includes:

- 3D CAD geometry (simplified)
- Steady-state thermal analysis followed by Static structural analysis
- Isotropic elastic materials: Oxygen-Free Electronic copper, aluminium, stainless steel, Silicon Carbide
- Contacts between parts (bonded and thermal)
- Fixed and frictionless supports
- Gravity
- Thermal loads, temperature condition, thermal fluid (water), convection to air

1. Introduction
2. Geometry
3. Simulation

2. Geometry

Model simplification

Drive beam girder + supports + cradles + arms

Main beam girder + supports + arms

4 Super Accelerating Structures (SAS)

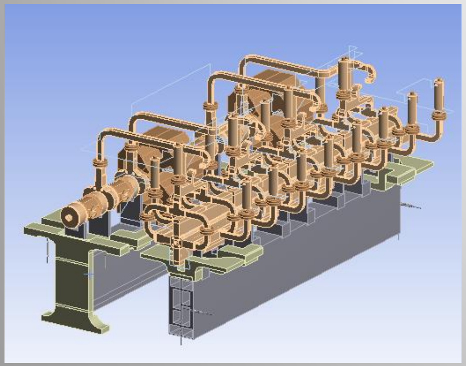
4 Power Extracting and Transferring Structures (PETS)

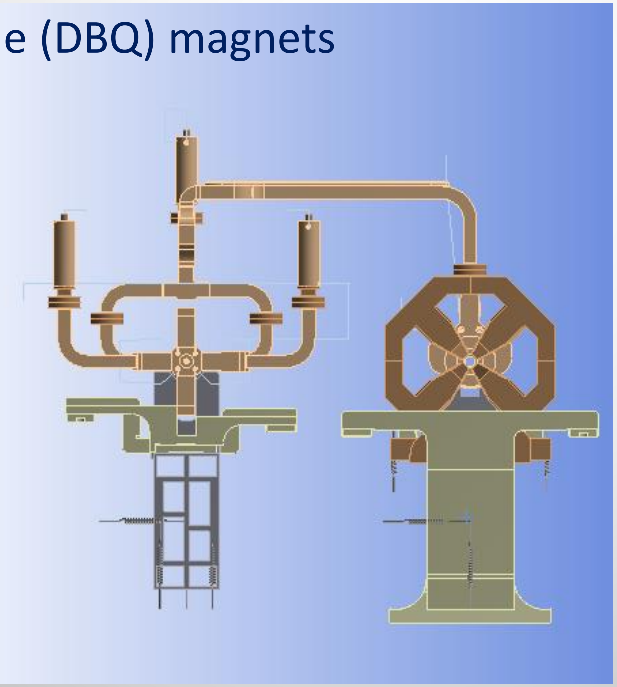
2 Drive Beam Quadrupole (DBQ) magnets

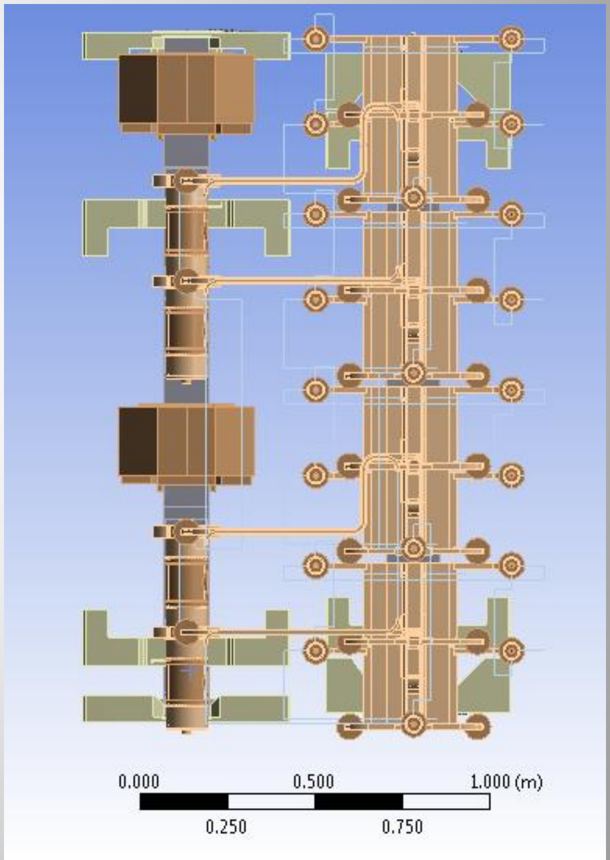
20 Compact Loads (CL)

Waveguides + flanges

Cooling system







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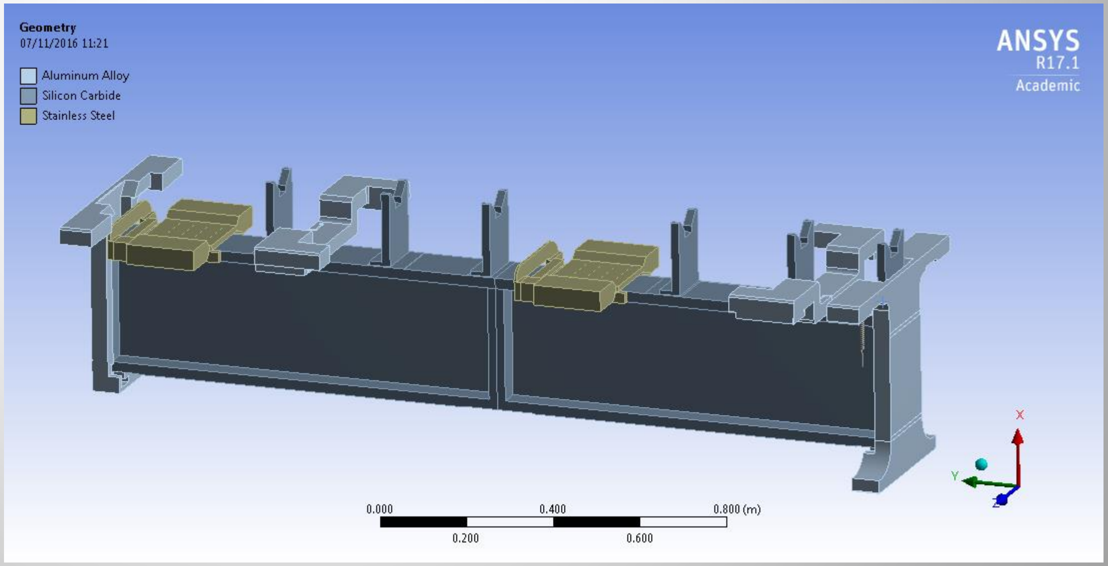
Cooling system

- Actuators, sensors etc. excluded



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2 Drive Beam Quadrupole (DBQ) magnets

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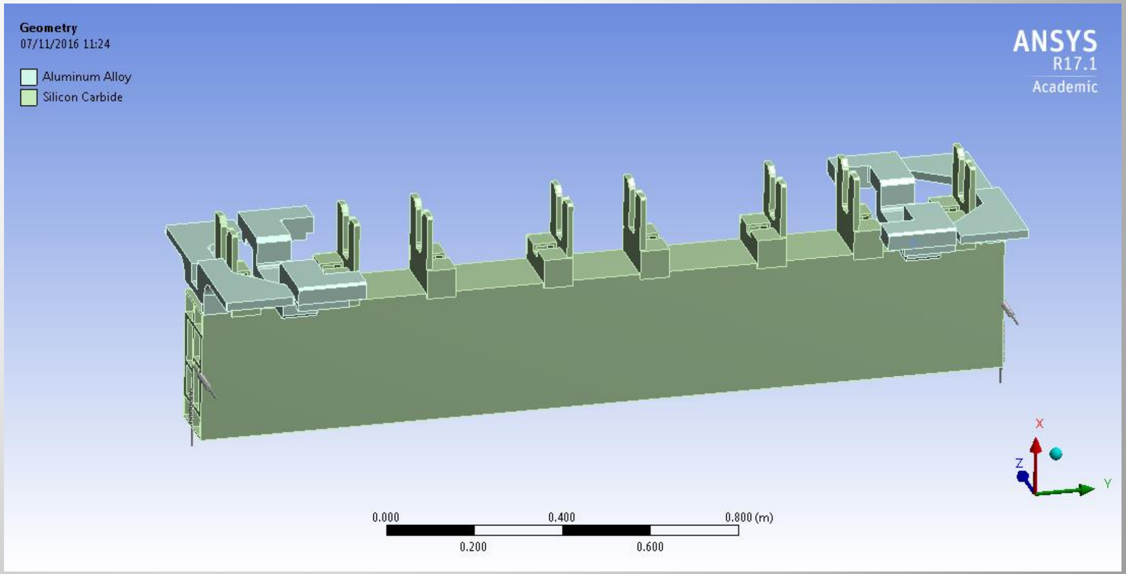
Waveguides + flanges

Cooling system

- Cradles, actuators, sensors etc. excluded



2. Geometry

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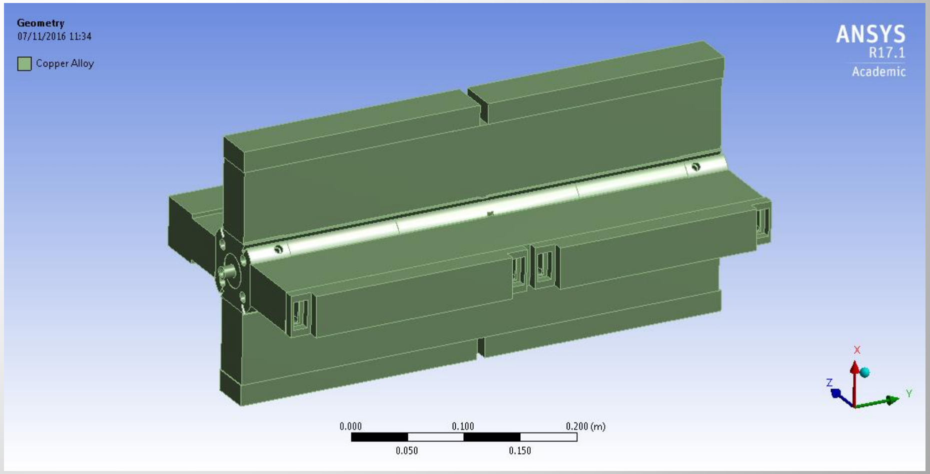
- Waveguides + flanges
- Cooling system

- Mock-up
- Damping plates excluded



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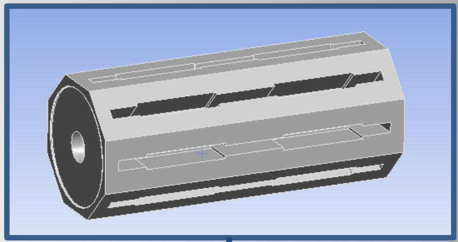

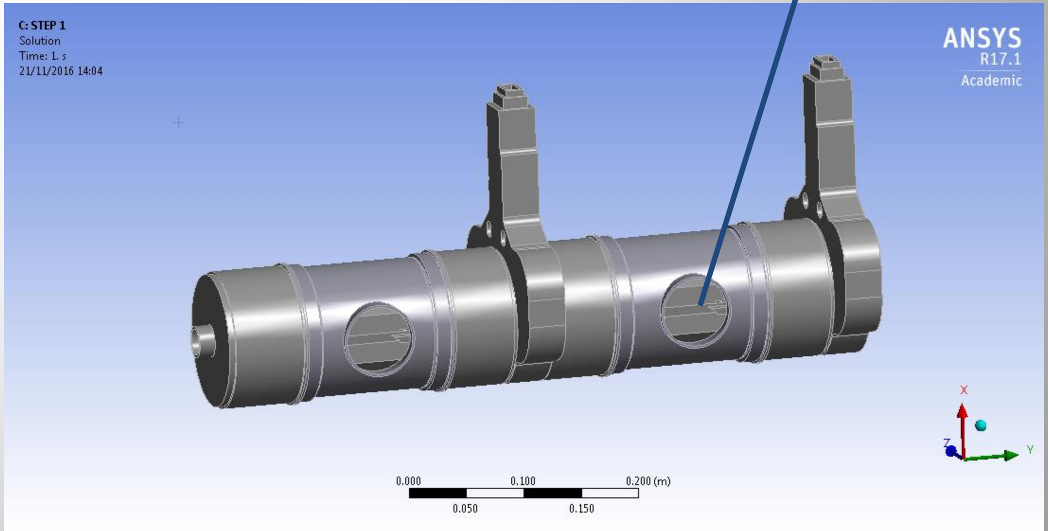

2. Geometry

Model simplification

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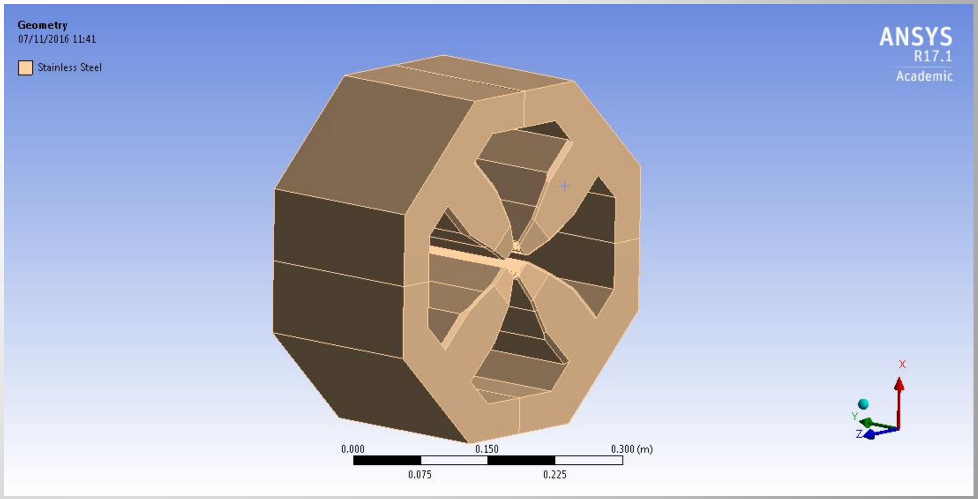
20 Compact Loads (CL)

Waveguides + flanges

Cooling system

- Coils excluded



2. Geometry

Model simplification

- Drive beam girder + supports + cradles + arms
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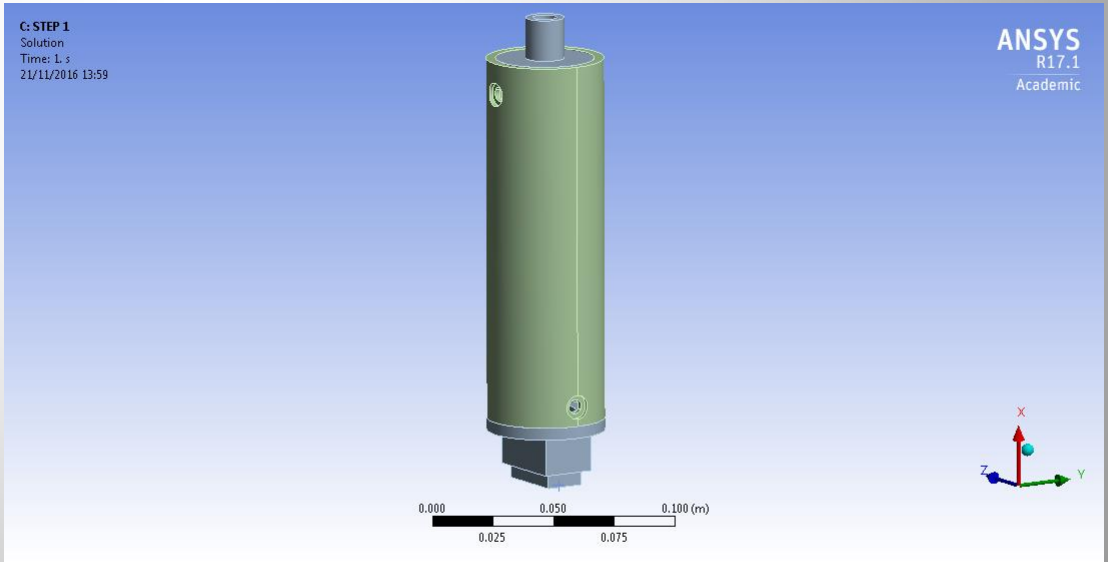
- **20 Compact Loads (CL)**
- Waveguides + flanges
- Cooling system



2. Geometry

Model simplification

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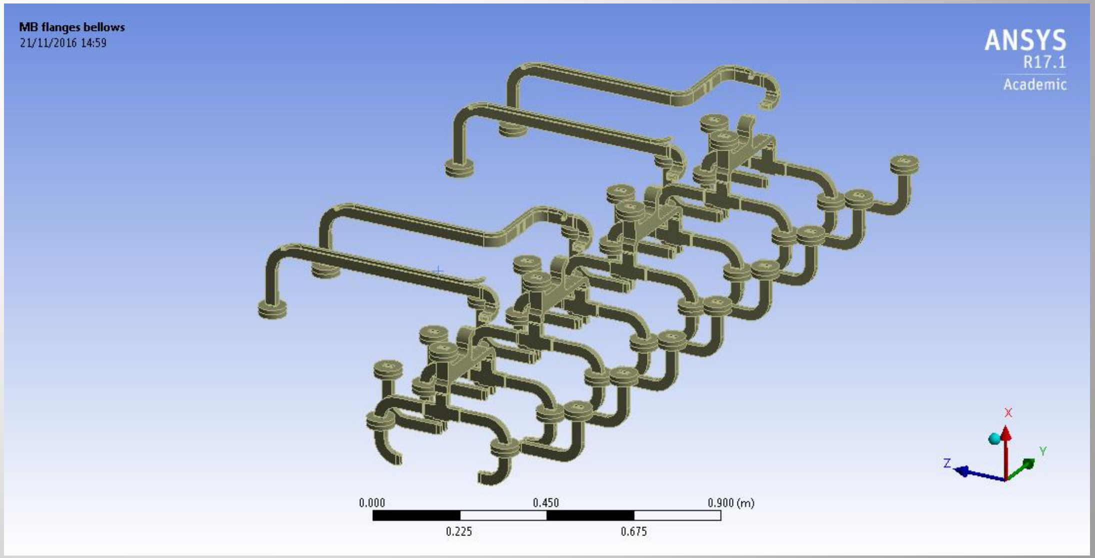
20 Compact Loads (CL)

Waveguides + flanges

Cooling system

- Bellows excluded



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Model simplification

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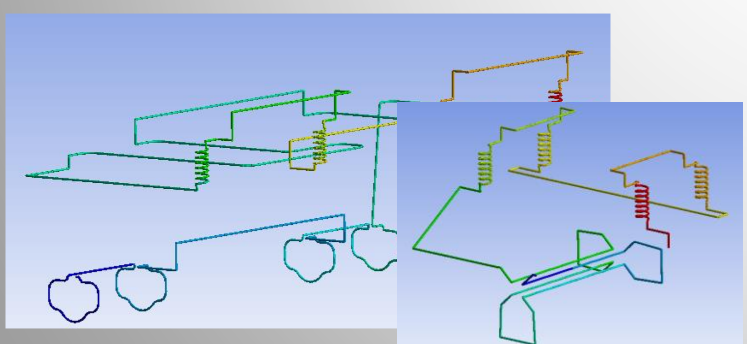


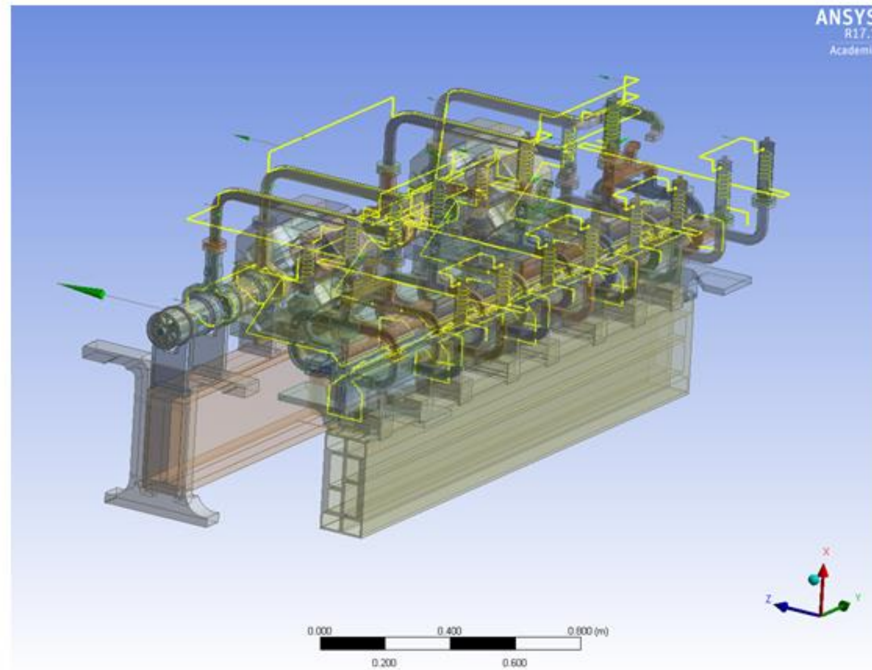


Figure 1. Simplified geometry model of CLIC lab module type 0_2. Cooling water network is highlighted with yellow.

1. Introduction
2. Geometry
3. Simulation

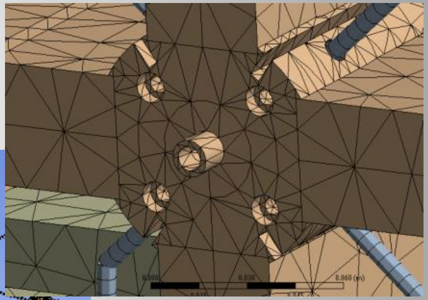
3. Simulation

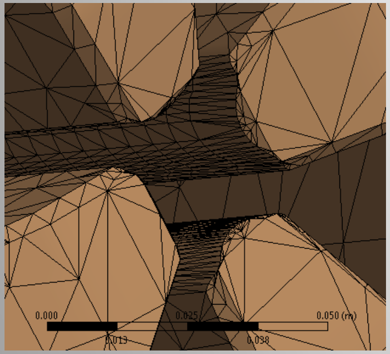
Finite element model

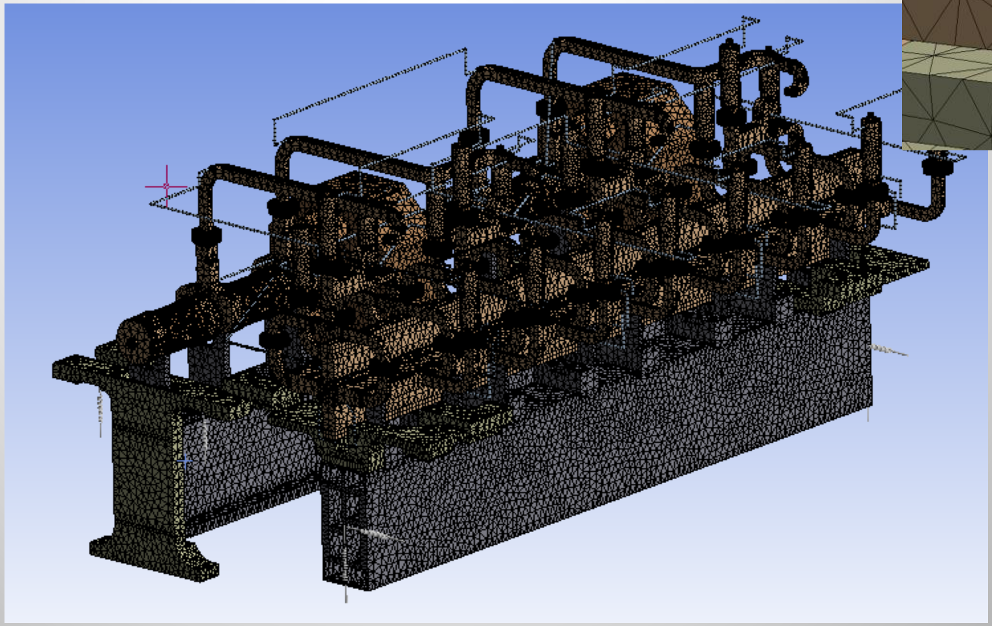
Geometry: After deleting, suppressing, and simplifying: 360 components

Contacts: Around 600 bonded and thermal contacts between components

Mesh: 2 million nodes, 1.1 million elements







3. Simulation

Analysis type

Combined Steady-State Thermal and Static Structural analysis

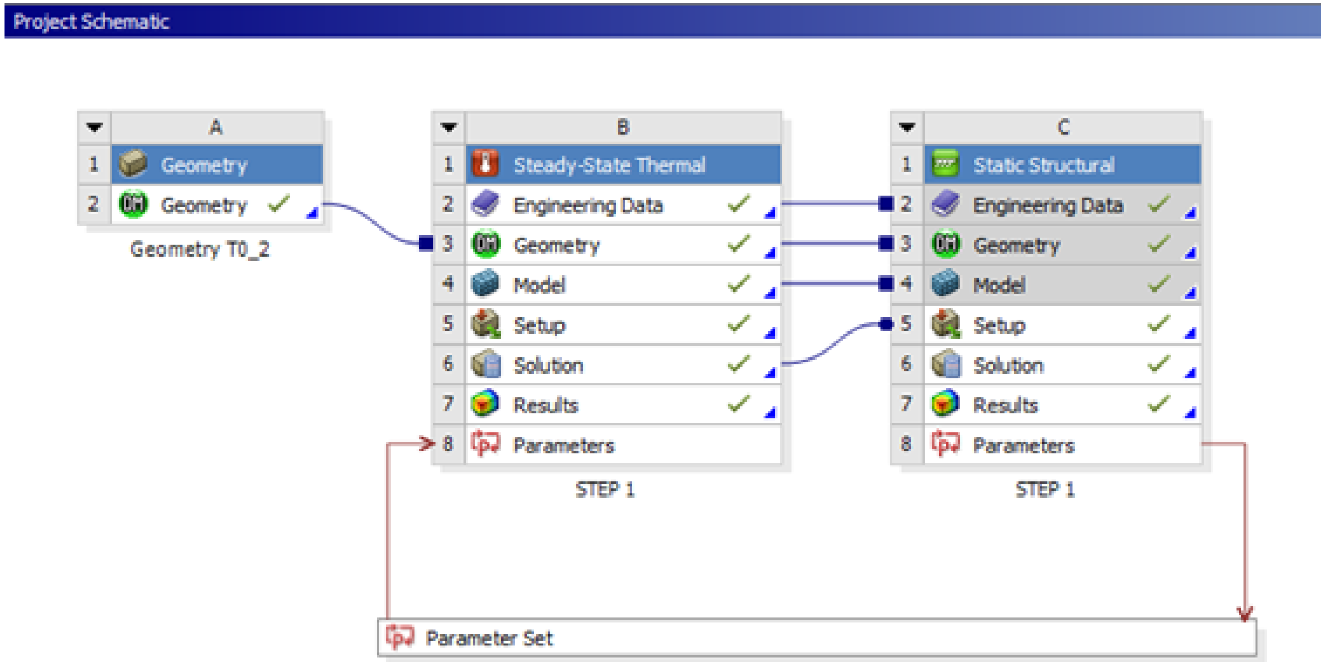


Figure 3. Project Schematic of the analysis in ANSYS 17.1 Workbench.

3. Simulation

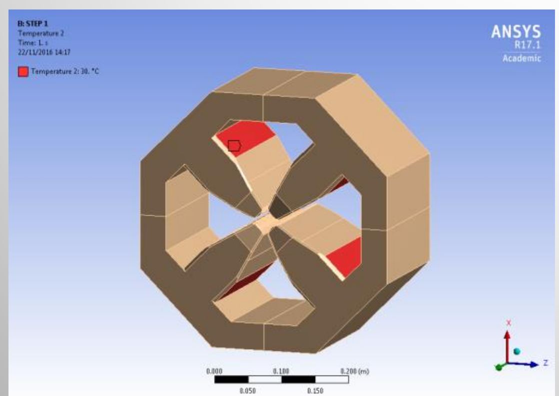
Thermal analysis

3. Simulation

Thermal analysis: heating elements

Structure	Heat power (W)
SAS	820
PETS	110
CL	150
DBQ	0*

*For DBQs, net heating power of coils is 0. Instead, temperature condition of 30°C is set to coil <-> yoke surfaces



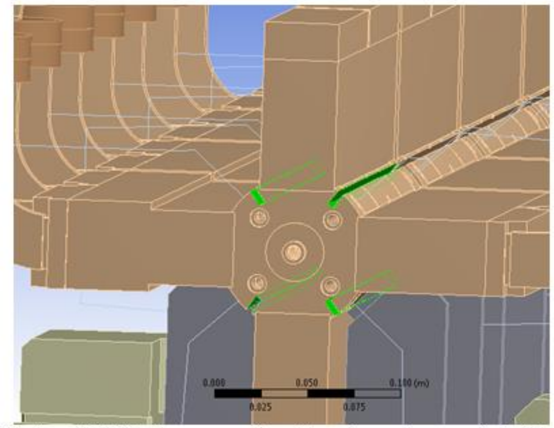
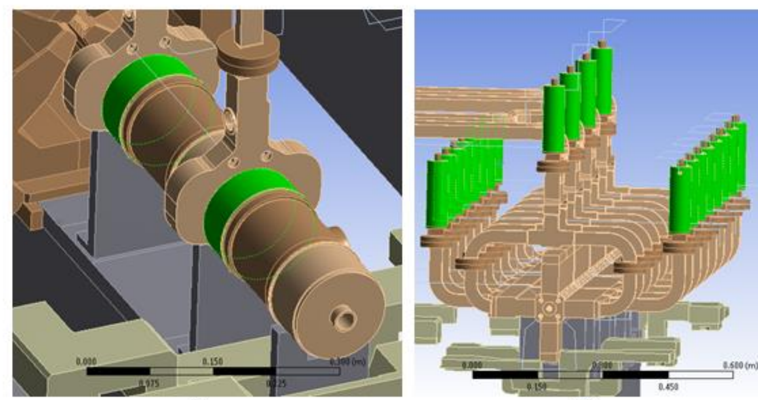


Figure 6. Heating of SAS in the grooves along the outer surfaces marked with green color.



(a) (b)

Figure 7. Heating of a) PETS and b) CLs on the outer surfaces marked with green color.

3. Simulation

Thermal analysis: test setup

Different cases can be studied, for example:

- CASE 0: Ambient temperature is 10°C, all components heating and cooling are active
- CASE 1: Ambient temperature is 35°C, all components heating and cooling are active

In both cases, the initial/reference temperature is the room temperature 20°C (relevant for the structural part of the study).

Constant heat transfer coefficient to air *h*: T = 10°C --> h = 55 W/(m² °C)
T = 35°C --> h = 12 W/(m² °C) [1,2,3]

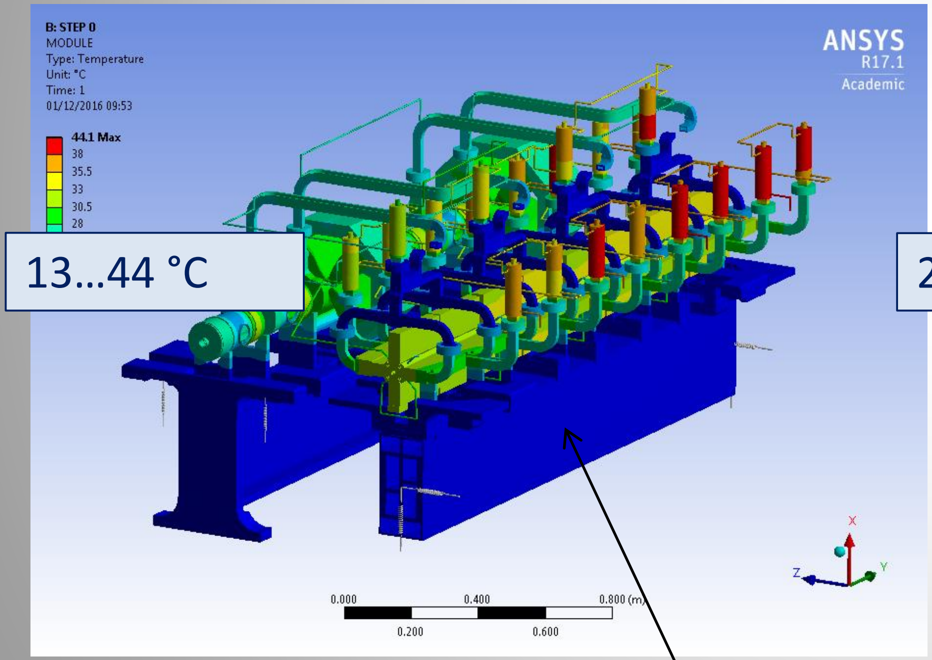
Case #	Input											
	T_∞ (°C)	HTC (W/ m² °C)	Heat power (%)				$T_{i,\ water}$ (°C)	Cooling water flow (m³/h)				
			SAS	PETS	CL			SAS1	SAS2	SAS3	SAS4	PETS
0	10	55	100	100	100		25	0.104	0.081	0.082	0.078	0.067
1	35	12	100	100	100		25	0.104	0.081	0.082	0.078	0.067

3. Simulation

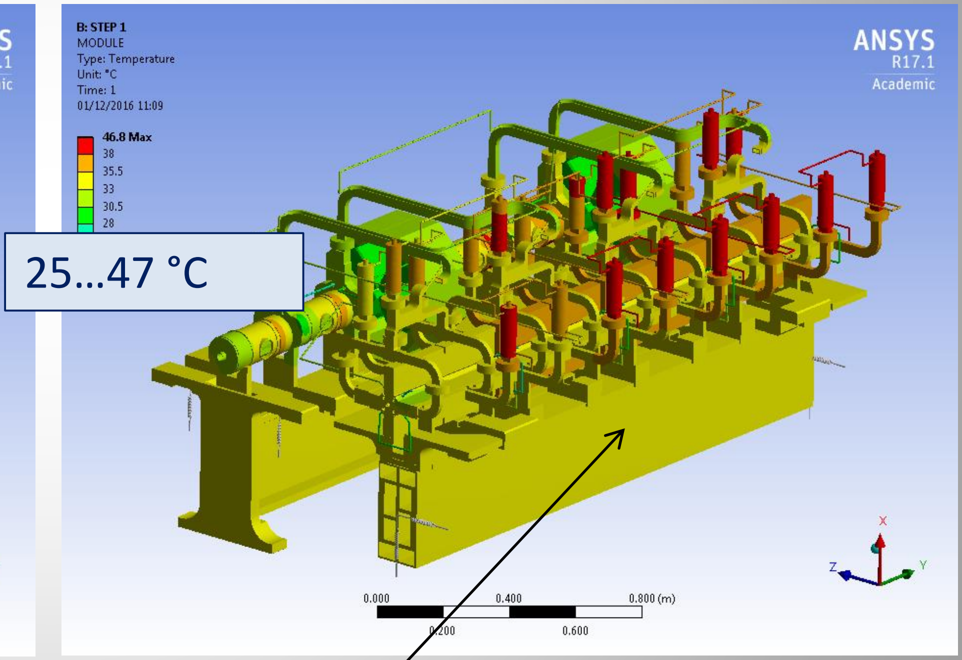
Thermal analysis: example results

Temperature distribution – whole module

<u>CASE 0</u>



<u>CASE 1</u>

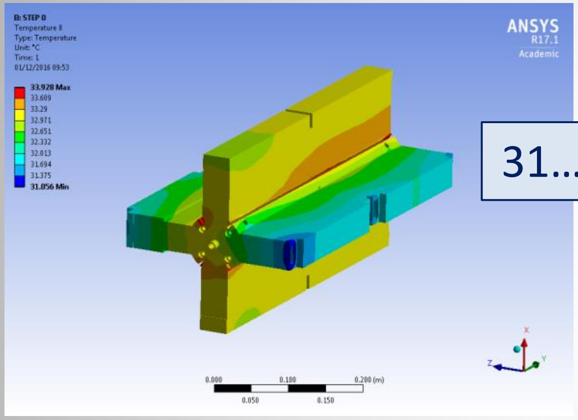
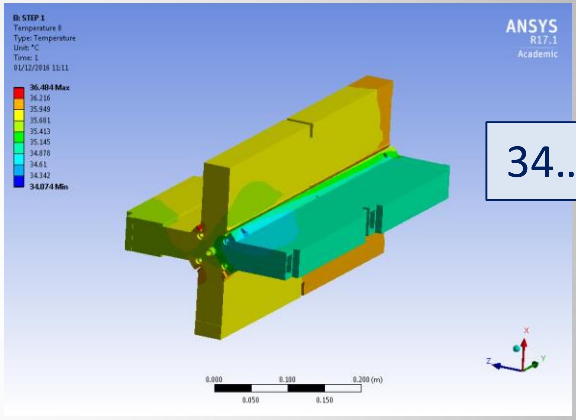
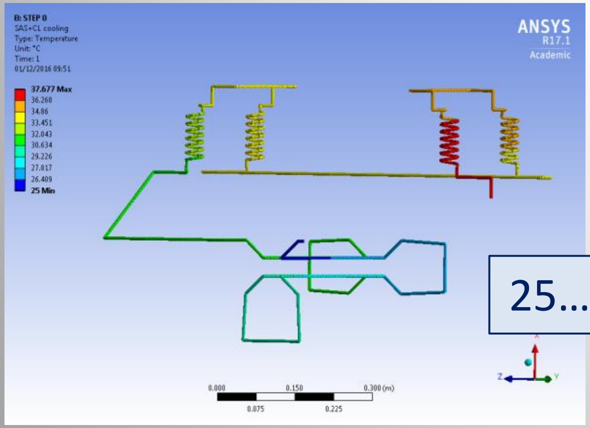
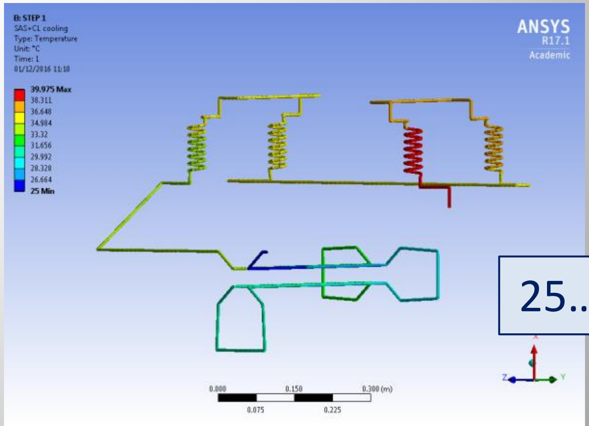


~ ambient temperature

3. Simulation

Thermal analysis: example results

Temperature distribution – SAS2 and the cooling water

CASE 0	CASE 1
 31…34 °C	 34…37 °C
 25…38 °C	 25…40 °C

3. Simulation

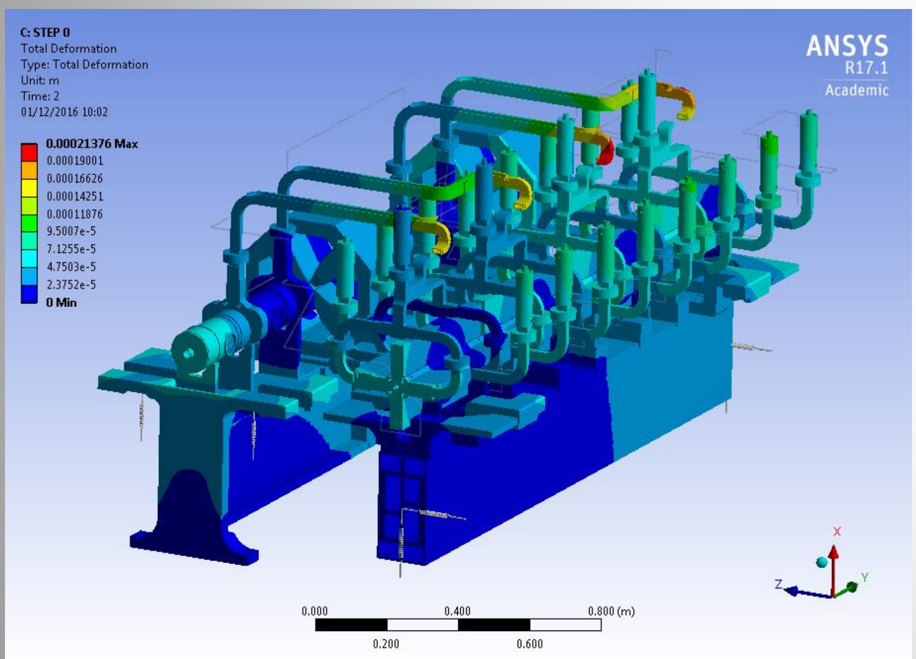
Structural analysis

3. Simulation

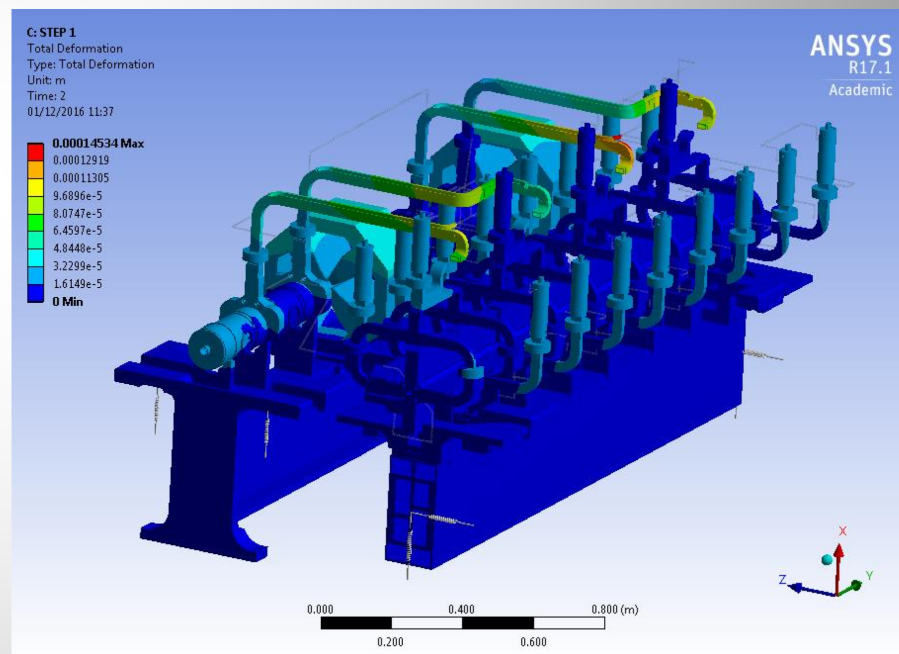
Structural analysis: results STEP 0

Total deformation – whole module

<u>CASE 0</u>



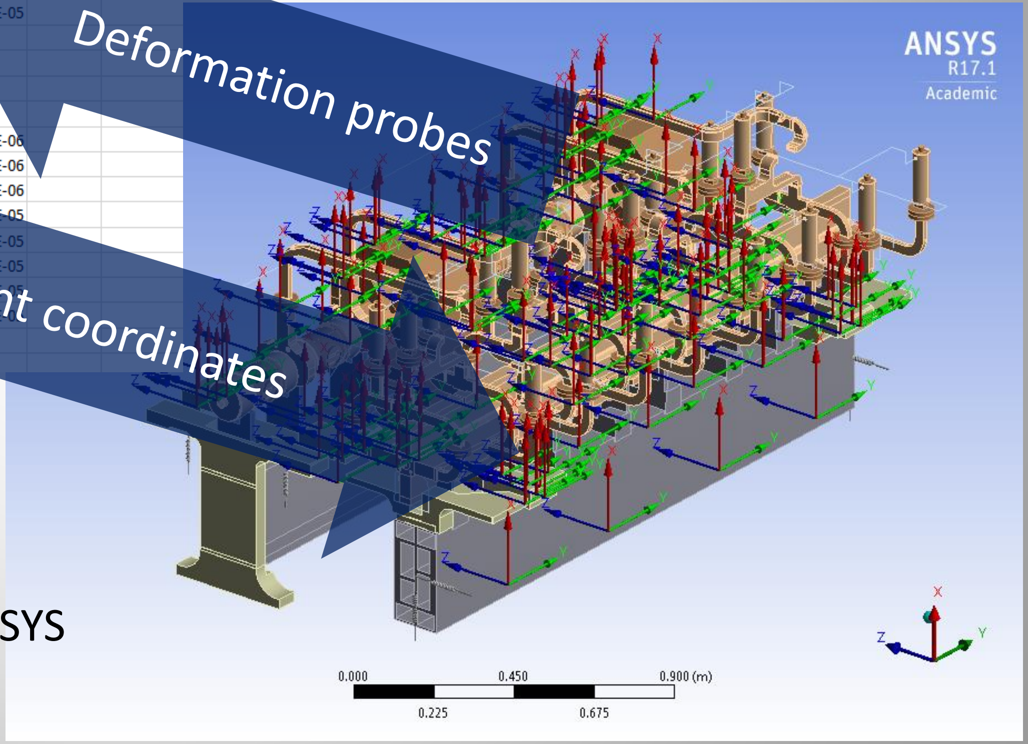
<u>CASE 1</u>

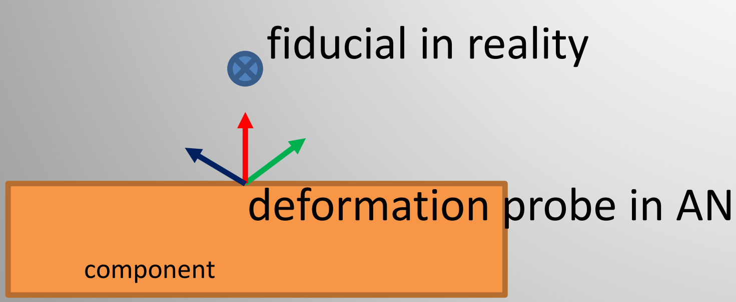


3. Simulation

Structural analysis: results to output parameters

A 9	9AS_middle	0.133	-753.170	-0.020			
	9AS_out	-0.003	-505.170	-0.022			
Supports fiducials 0.5" **10 AS**	10AS1	1.034	-460.278	135.913	8.95E-05	-1.31E-05	-4.62E-06
	10AS2	1.497	-265.245	135.984	9.04E-05	5.15E-05	-4.74E-06
	10AS3	-0.419	-37.511	135.987	8.98E-05	0.0001272	-4.22E-06
	10AS4	32.919	-362.668	75.799	7.44E-05	1.95E-05	-1.02E-05
	10AS5	32.953	-141.073	76.026	7.50E-05	9.25E-05	-1.02E-05
	10AS6	75.396	-248.082	33.124	5.57E-05	5.73E-05	-2.74E-05
	10AS7	136.037	-387.223	-4.109	4.71E-05	1.17E-05	-4.31E-05
	10AS8	136.080	-141.912	-2.255	4.81E-05	9.20E-05	-4.34E-05
Axis **10 AS**	10AS_high	-0.112	-249.099	199.971			
	10AS_in	-0.003	-493.108	-0.019			
	10AS_middle	0.015	-249.108	-0.029			
	10AS_out	0.032	-5.108	-0.040			
Supports fiducials 0.5" **11 AS**	11AS1	0.210	27.194	136.135	9.00E-05	2.24E-05	-4.57E-06
	11AS2	-0.653	240.396	136.072	9.11E-05	9.30E-05	-4.16E-06
	11AS3	-1.326	482.679	136.011	9.02E-05	0.0001735	-4.23E-06
	11AS4	33.171	132.308	82.072	7.71E-05	5.74E-05	-1.04E-05
	11AS5	33.298	394.776	81.017	[illegible]	0.0001441	-1.06E-05
	11AS6	69.808	253.593	32.807	[illegible]	[illegible]	-2.59E-05
	11AS7	136.046	140.413	3.602	5.04E-05	6.03E-05	[illegible]
	11AS8	136.052	382.744	4.471	5.10E-05	0.0001397	[illegible]
is AS	11AS_high	-0.033	255.099	199.964			
	11AS_in	0.000	11.099	-0.035			





Summary and outlook

Thermal-structural analysis of CLIC lab module T0#2 is done with Finite Element Method using ANSYS 17.1

Model simplification and defining the settings for the analysis are documented thoroughly in a CLIC – Note –

Plenty of room for improvements, for example:

Conductivity by air flow should be studied more deeply, now constant HTC is assumed: a combined simulation? ANSYS Fluent –> Thermal –> Structural

Now all bonded contacts are stiff; in reality some of the contacts are more flexible and also frictional contacts exist.

Thanks!

References:

[1] L. Kortelainen, 2013, Thermo-mechanical modelling and experimental validation of CLIC prototype module type 0, Master's thesis, Department of Mechanical Engineering, University of Oulu, Finland.

[2] R. Nousiainen *et al.*, 2010, Studies on the Thermo-Mechanical behaviour of the CLIC Two-Beam Module. Linear Accelerator Conference 2010, Tsukuba, Japan.

[3] R. Raatikainen, 2011, Modelling of the thermo-mechanical behavior of the two-beam module for the compact linear collider, Master's thesis, Department of Mechanics and Design, Tampere University of Technology, Finland.

EXTRA

Structural analysis: boundary conditions

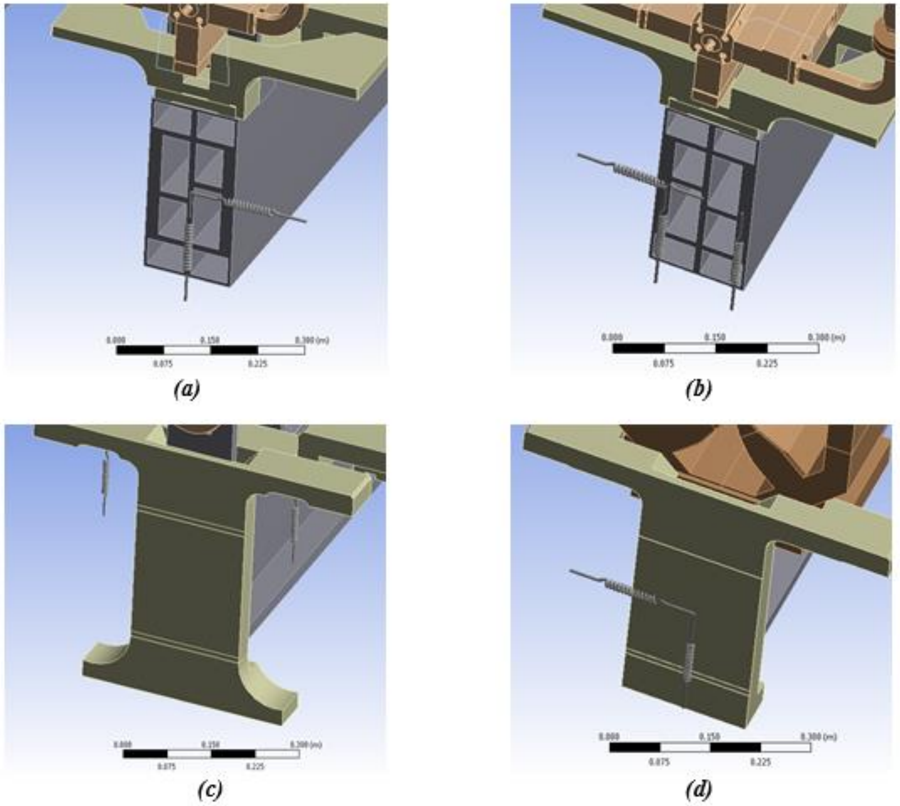


Figure 5. Springs replacing the actuators in (a) MB master cradle, (b) MB slave cradle, (c) DB master cradle, and (d) DB slave cradle.

EXTRA

Structural analysis: boundary conditions

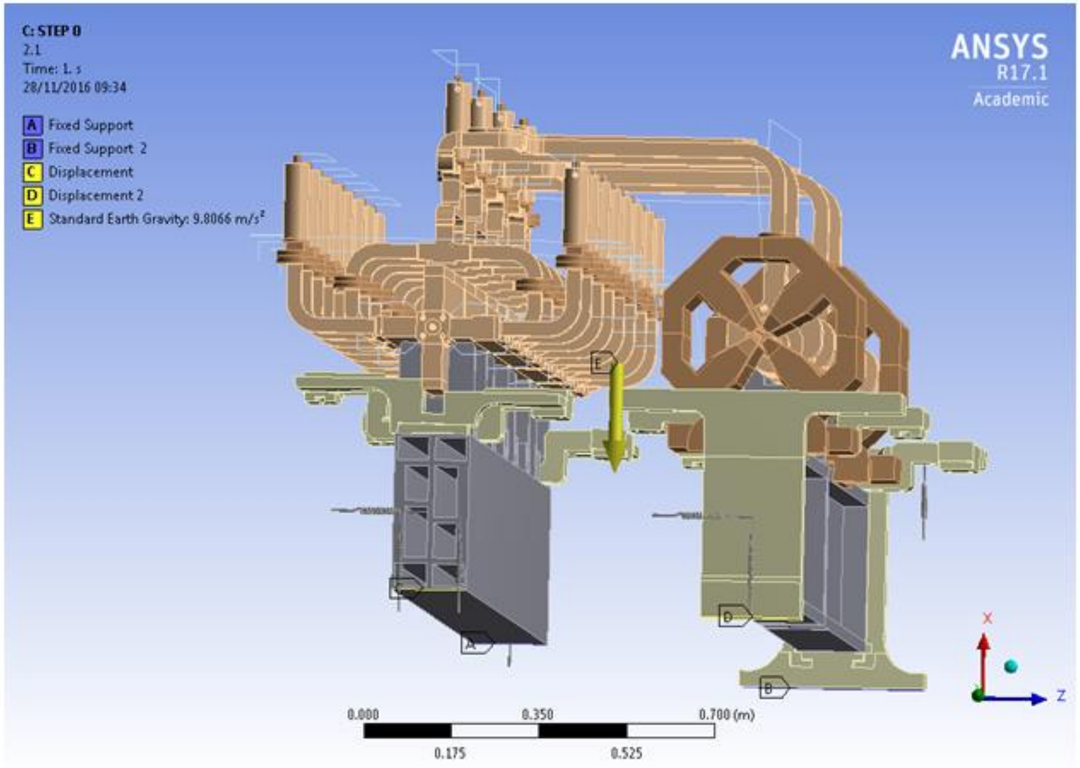


Figure 8. Definition of the mechanical supports and loads for structural analysis. Here (A) and (B) are fixed supports on edges at the end of the MB and DB girders, (C) and (D) are displacement supports on edges in the end of both girders with x-directional movement blocked, (E) is the standard earth gravity.

EXTRA

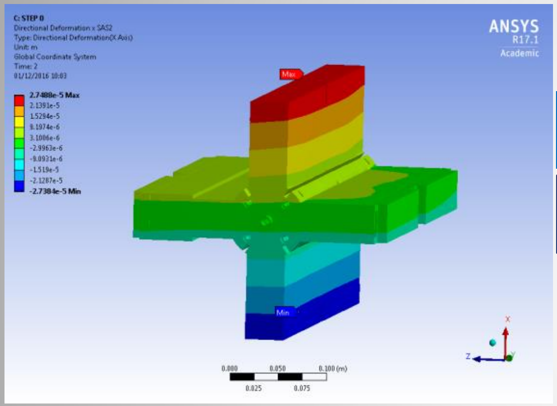
Structural analysis: example results

Directional deformations – SAS2

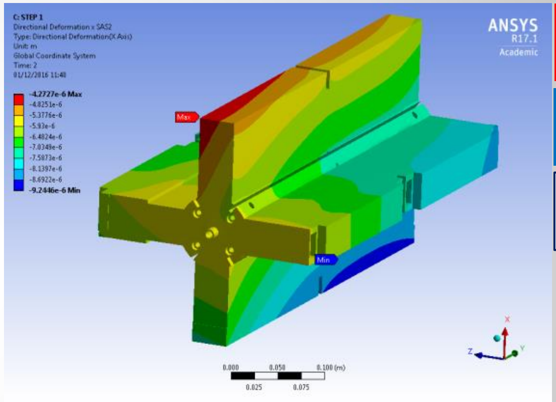
CASE 0

CASE 1

x

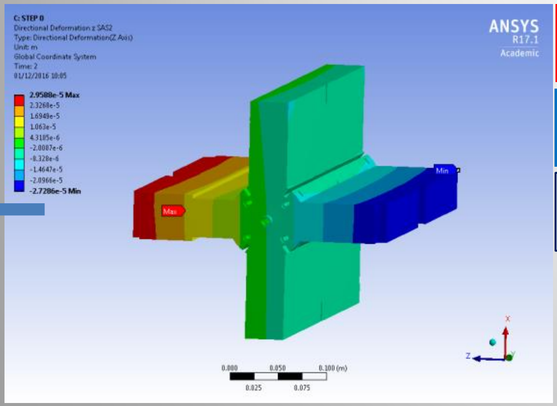


Max = +27 µm
Min = -27 µm
Iris -1 µm

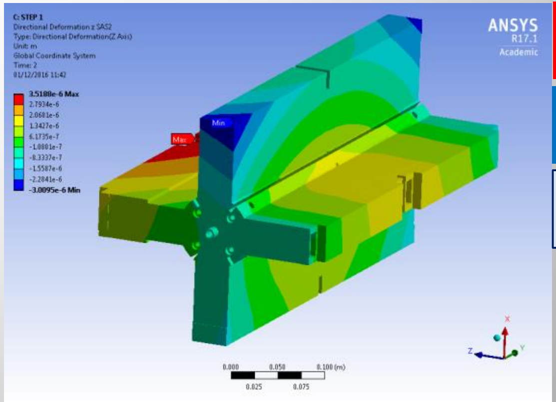


Max = -4 µm
Min = -9 µm
Iris -6 µm

z



Max = +17 µm
Min = -15 µm
Iris -1 µm



Max = +3 µm
Min = -3 µm
Iris -1 µm