Mechanical studies of the cryomodule

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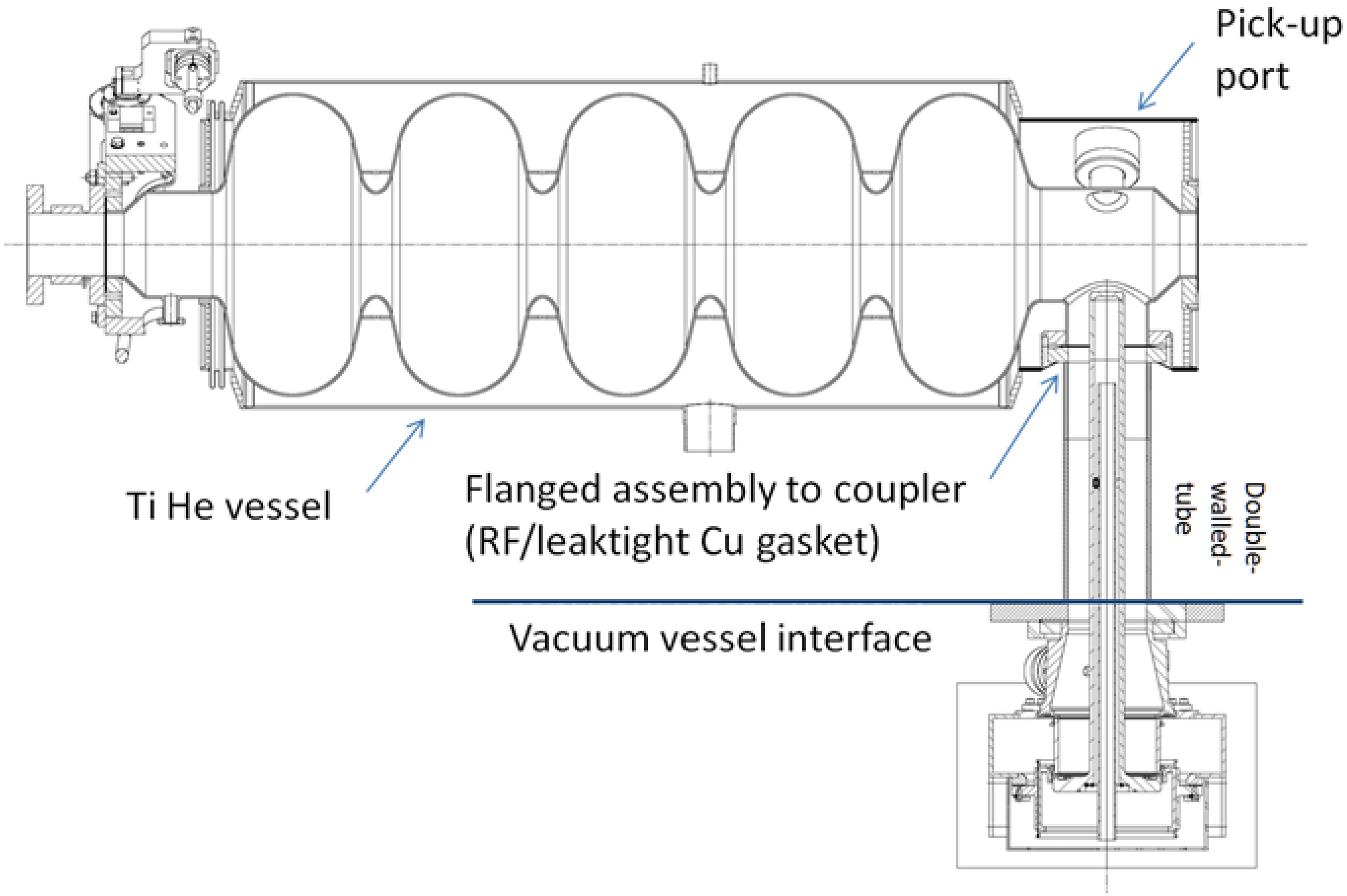
Contents

1. Introduction

Calculations carried out with the aim of evaluating possible support solutions for the components of the SPL cryomodule and the SPL test cryostat.



1. Introduction

Transversal position tolerance of cavities inside cryostat

BUDGET OF TOLERANCE			
Step	**Sub-step**	**Tolerances (3σ)**	**Total envelopes**
Cryo-module assembly	Cavity and He vessel assembly	*± 0.1 mm (TBD)*	Positioning of the cavity w.r.t. beam axis **± 0.5 mm**
	Supporting system assembly	*± 0.2 mm (TBD)*	
	Vacuum vessel construction	*± 0.2 mm (TBD)*	
Transport and handling (± 0.5 g any direction)	N.A.	*± 0.1 mm (TBD)*	Stability of the cavity w.r.t. beam axis **± 0.3 mm**
Testing/operation	Vacuum pumping	*± 0.2 mm (TBD)*	
	Cool-down		
	RF tests		
	Warm-up		
	Thermal cycles		

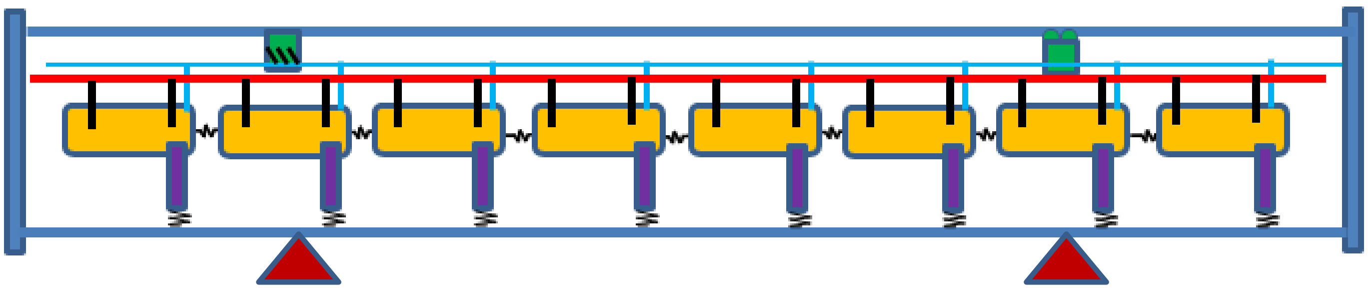
Construction precision (Cryo-module assembly)

Long-term stability (Transport and handling; Testing/operation)

1. Introduction

Possible supporting schemes

"Standard" supporting scheme



Two-support preferrable → isostatic (=well defined forces on supports)

...but is cavity straightness enough?? If not...

RF coupler (with bellows)

Invar longitudinal positioner

Inertia beam

Fixed support

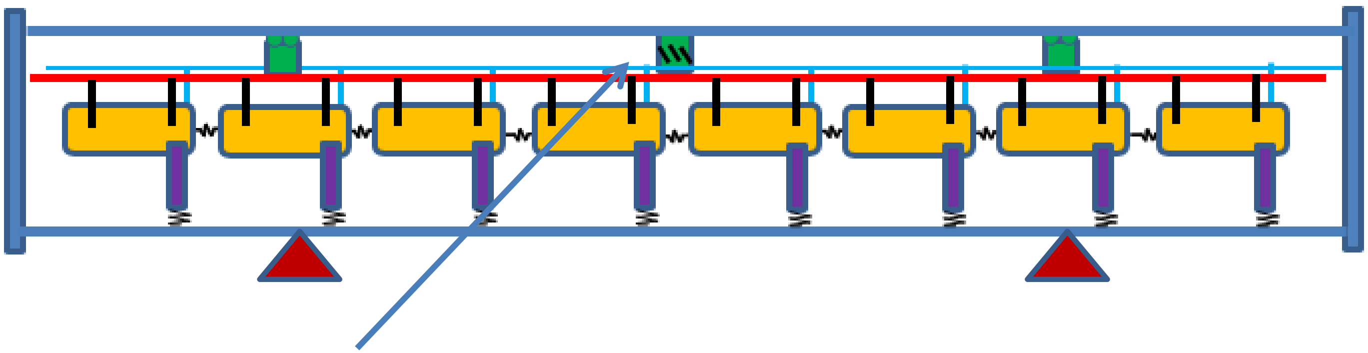
Sliding support

External supports (jacks)

1. Introduction

Possible supporting schemes

“Standard” supporting scheme



...add 3rd support → becomes hyperstatic (= forces depend on mech. coupling vessel/inertia beam)

RF coupler (with bellows)

Invar longitudinal positioner

Inertia beam

Fixed support

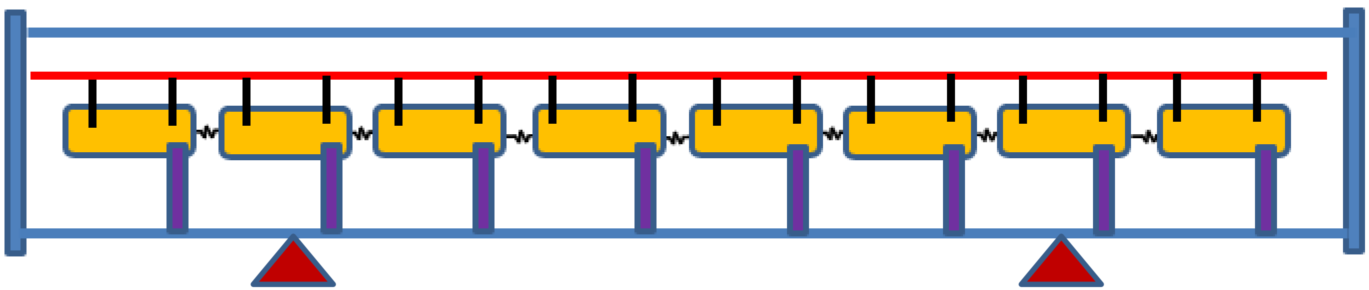
Sliding support

External supports (jacks)

1. Introduction

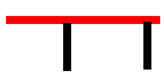
Possible supporting schemes

Alternative: coupler supporting scheme



...the coupler is also a supporting/aligning element


RF coupler + longitudinal positioner + vertical support


Intercavity support structure


External supports (jacks)

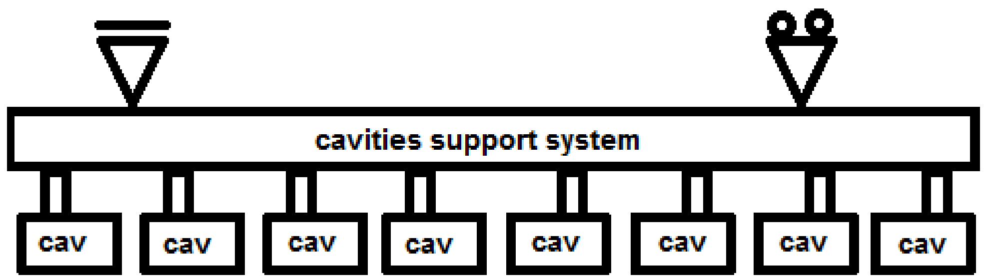
2. Supporting system – required stiffness

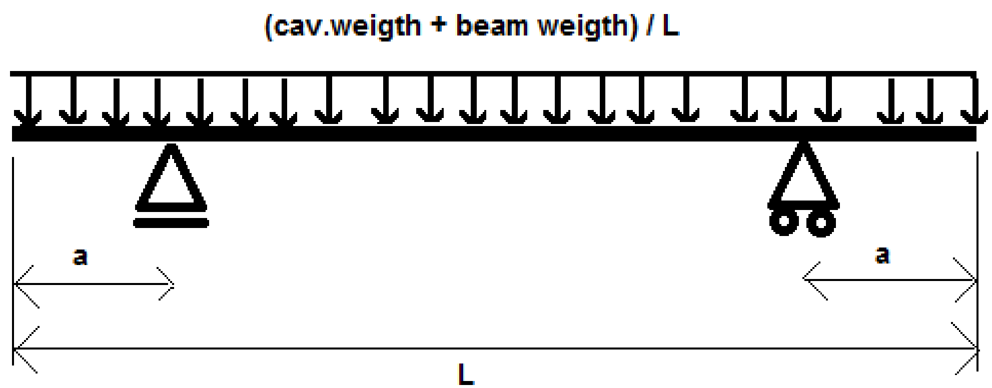
Calculations performed with the aim of estimating the stiffness which the support system ("Standard "supporting solution) of the SPL cavities would have to provide for the string of cavities to be kept inside a certain alignment tolerance.

- Beam simply and symmetrically supported on two points, loaded by the weight of the cavities and by its own weight.

- Loads are distributed uniformly along the beam

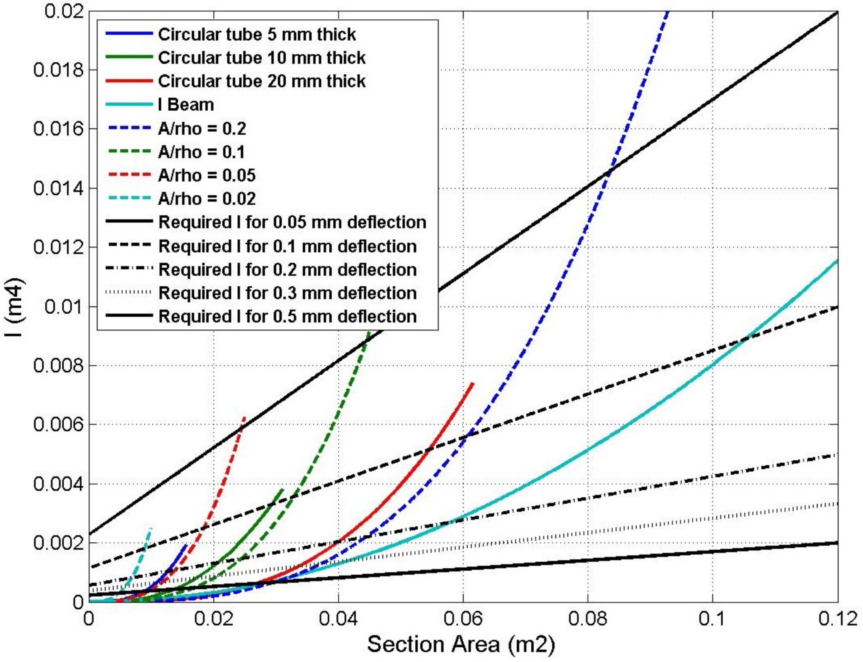
-The cavities and the supports are considered to be rigid -maximum beam deflection is a measure of the maximum cavity misalignment.

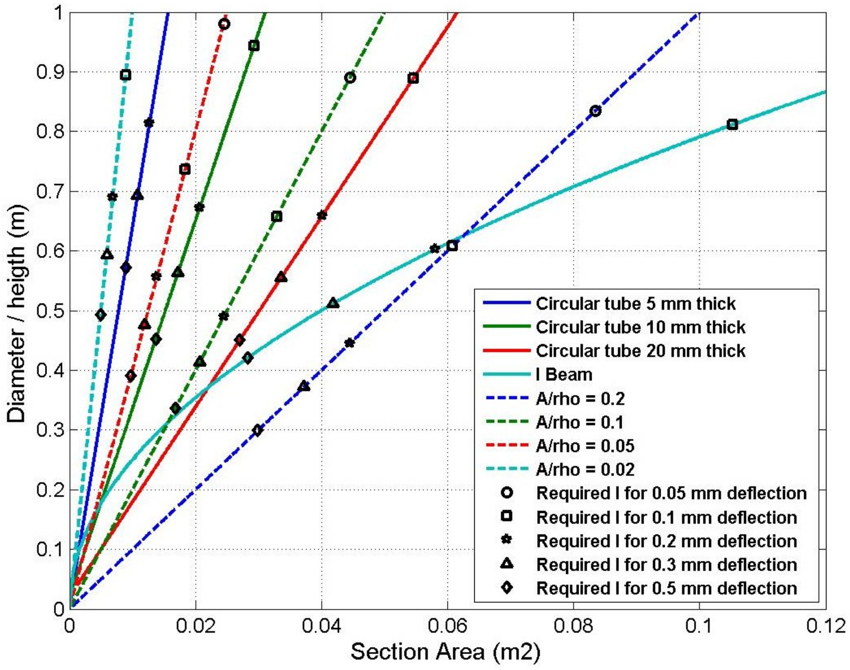




2. Supporting system – required stiffness

Required stiffness – different cross sections





L=13 m, m_{cav}=200 Kg, n_{cav}=8 , g=9.8 m/s²

Stainless steel 304 L: ρ=8000 kg/m³; E=1.93e¹¹ Pa

2. Supporting system – required stiffness

Third support? – Comparison with 2 supports

	S [m^2]	*I* [m^4]	Deflection; 2 supports (analytical) [*mm*]	Deflection; 3 supports (FE beam analysis) [*mm*]
Circular tube *tck. 6 mm diam. 300 mm*	0.0055	5.99E-05	2.3	0.358
Circular tube *tck.* 12 *mm diam. 1000 mm*	0.0372	4.55E-03	0.075	0.018

- Three vertical displacements (simple supports)

- Loads remain the same.

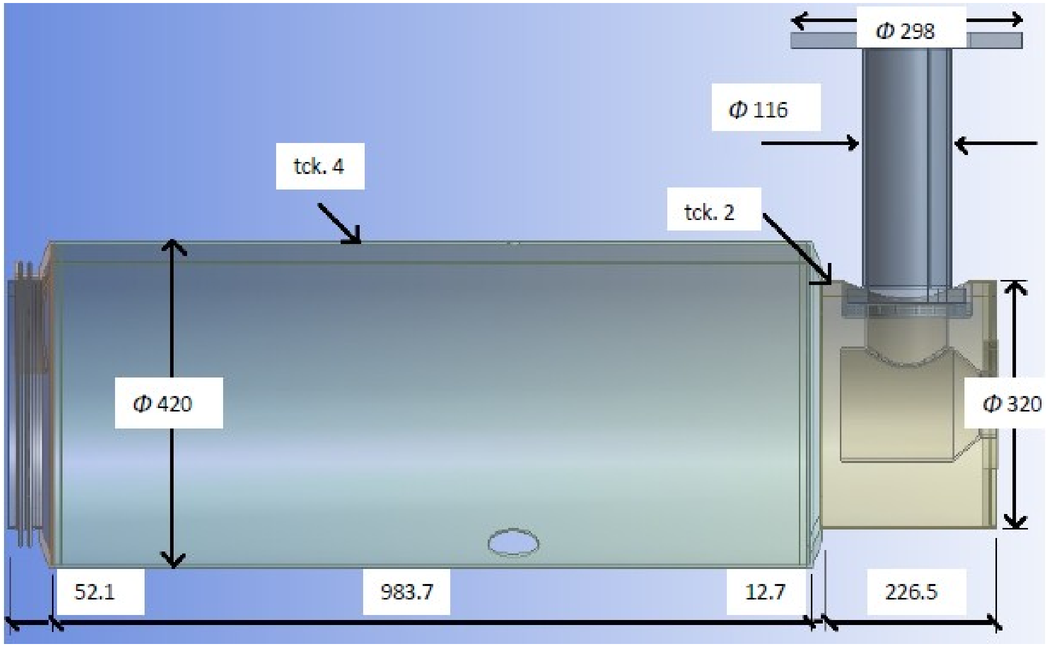
- One support in the middle of the beam, the other two at a distance of 0.16 *L* from each end of the beam.

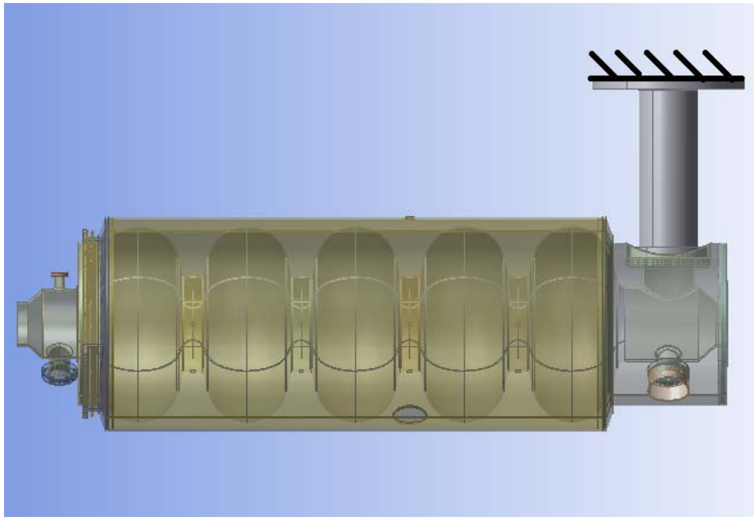
3. Power coupler as support

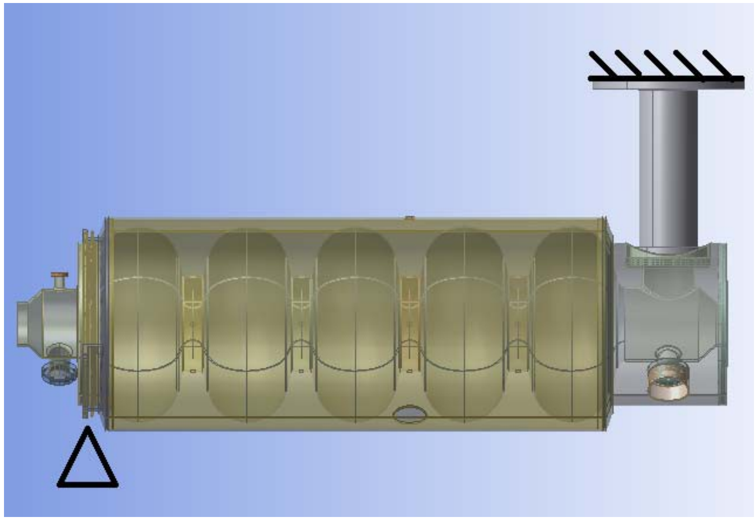
Two different support scenarios : 1. cavity supported only by a fixed support on the Power Coupler flange, 2. cavity supported by the PC and by a vertical support on the other extremity of the Helium Vessel.

Loads: Weights of the represented parts (1068 N) plus weight of the tuner (147N)

Materials: Titanium for the Helium Vessel and Stainless steel for the other parts.

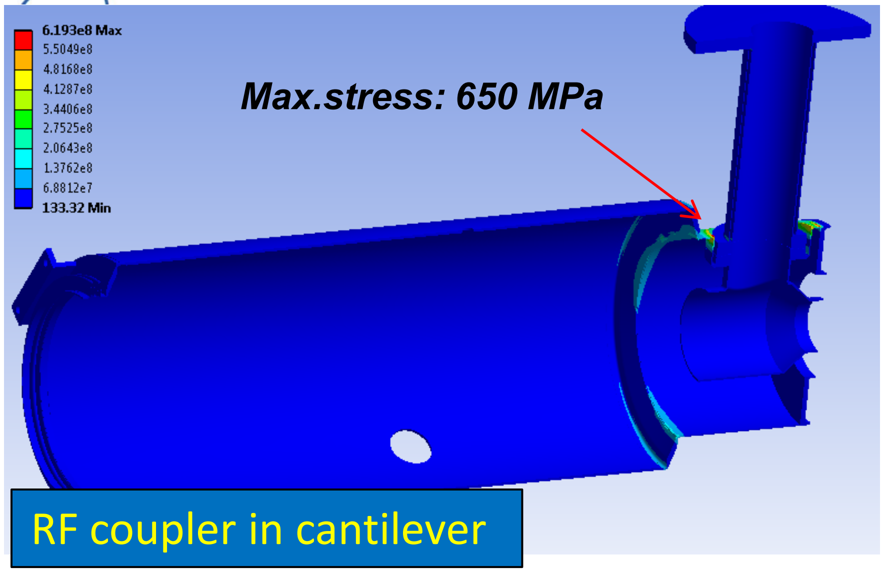


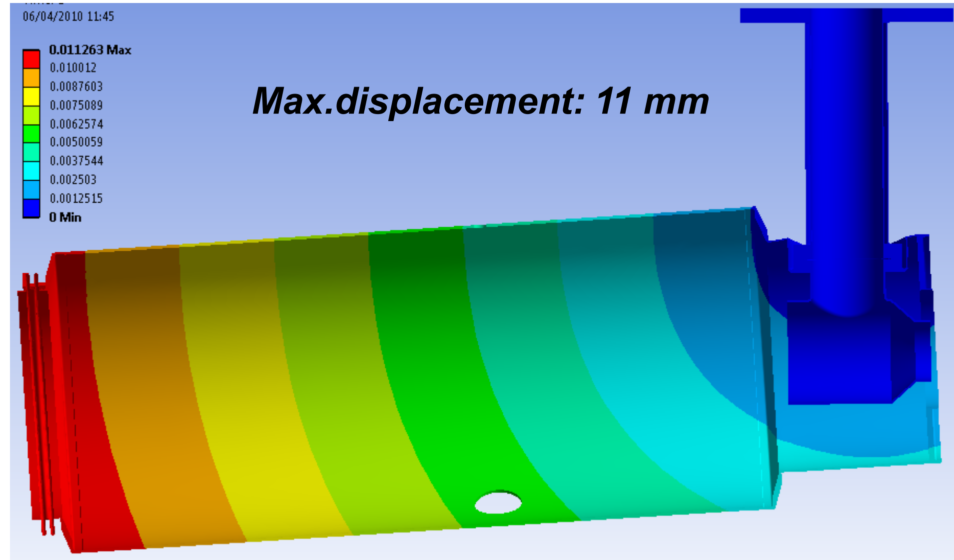


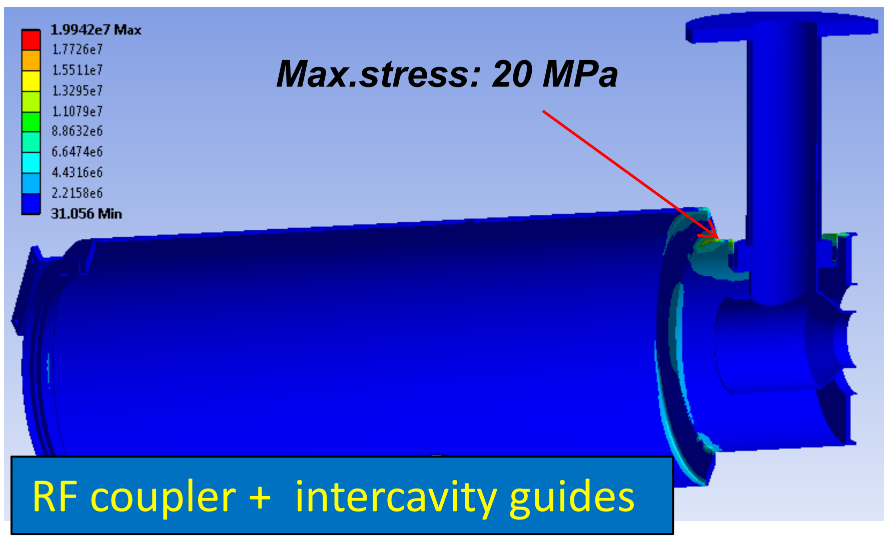


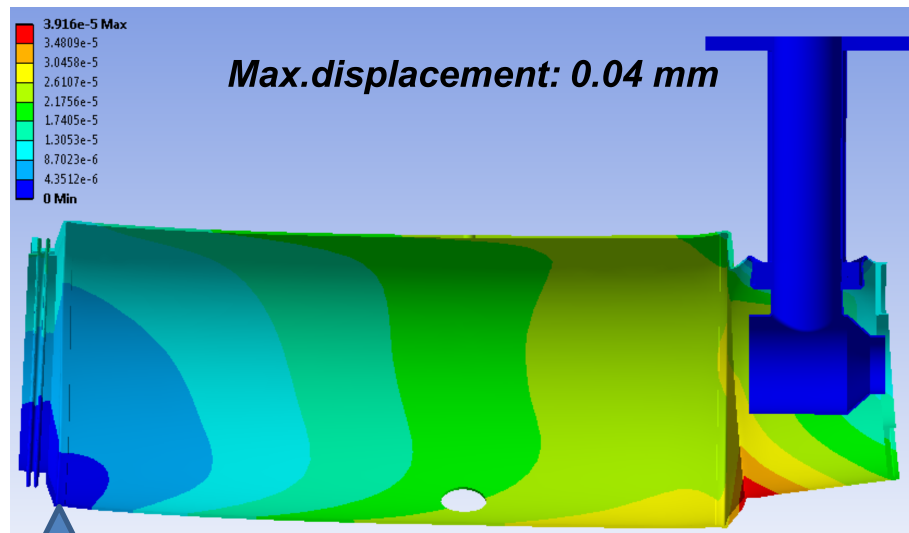
These models are previous versions.

3. Power coupler as support









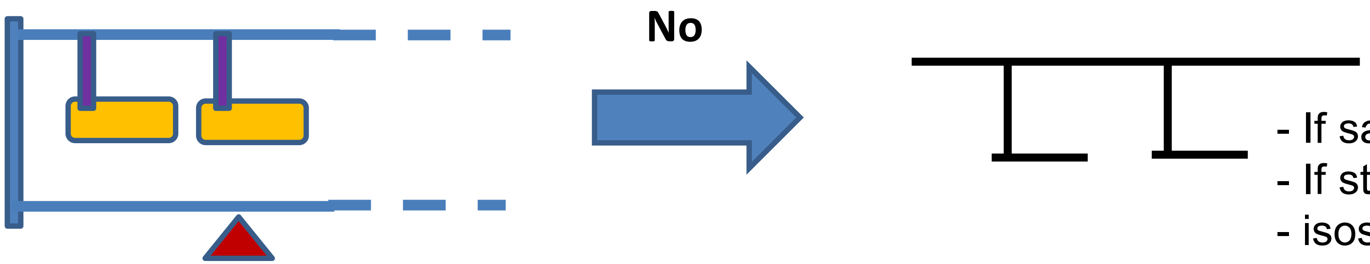
von Mises stress (Pa)

Total displacement (m), amplification of 1100x

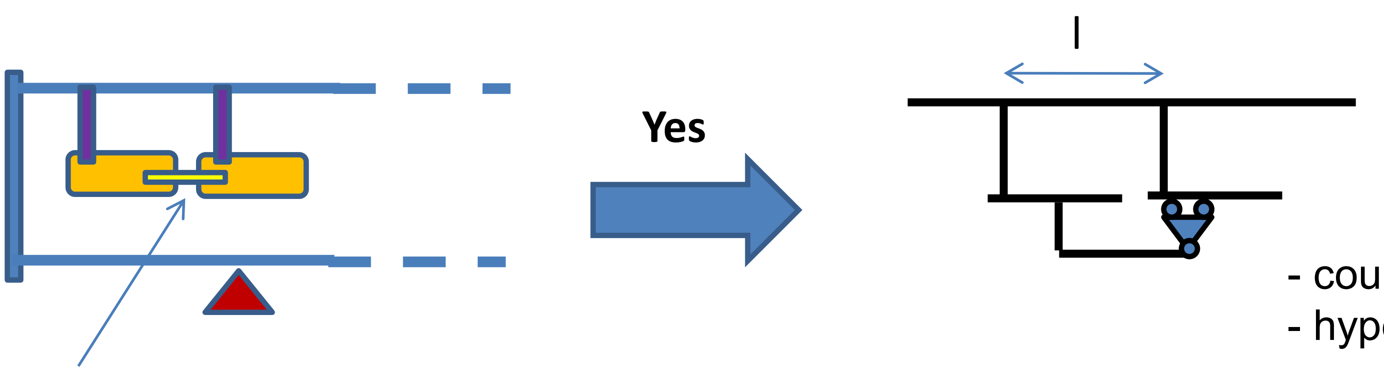
3. Power coupler as support

Coupler supporting scheme

Layout | Equivalent sketch



- If sag small enough
- If strenght OK
- isostatic

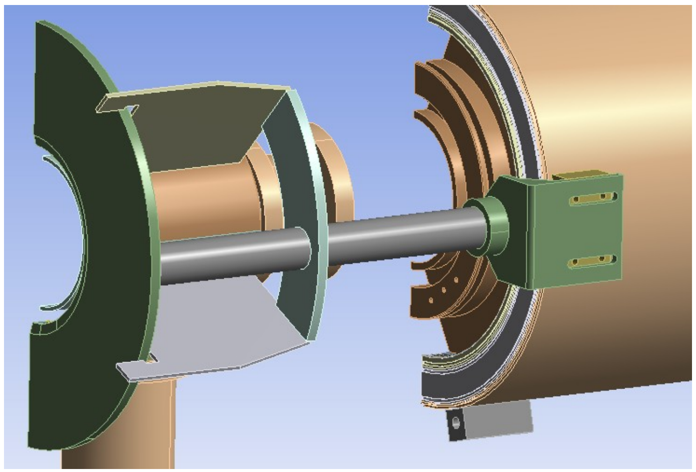


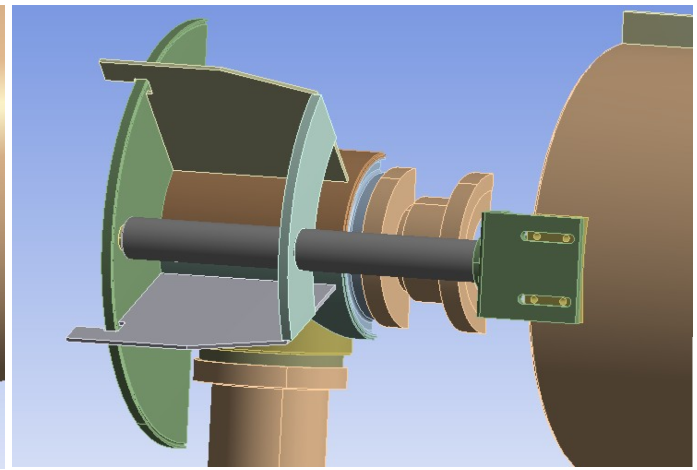
- couple cavities
- hyperstatic

inter-cavity guides

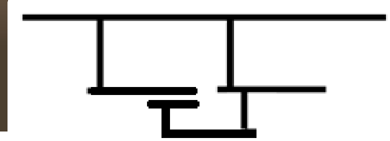
4. Inter-cavity sliding support

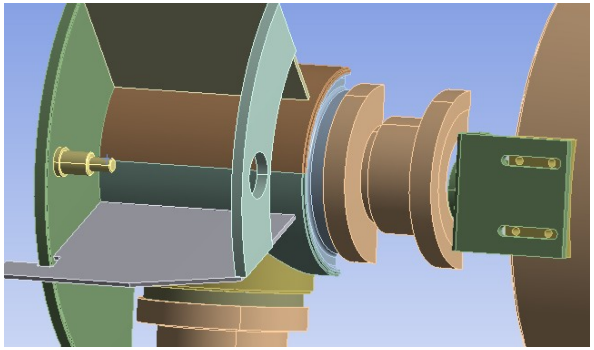
Conceptual design:

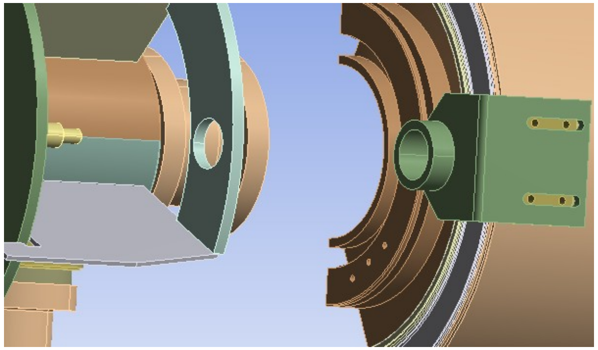


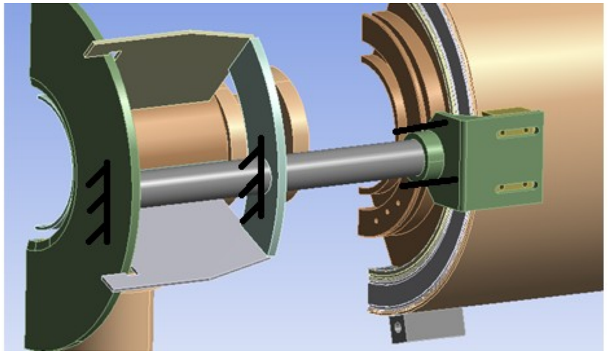


Scheme of link between cavities:





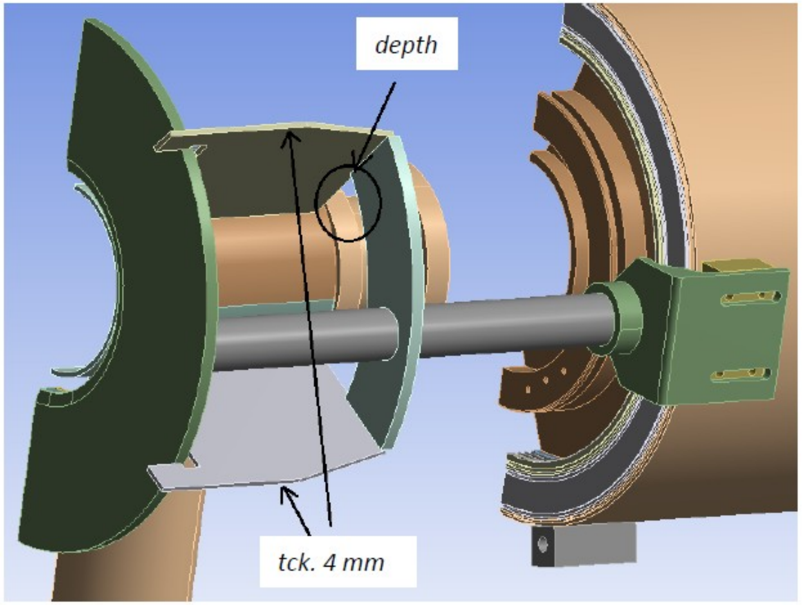


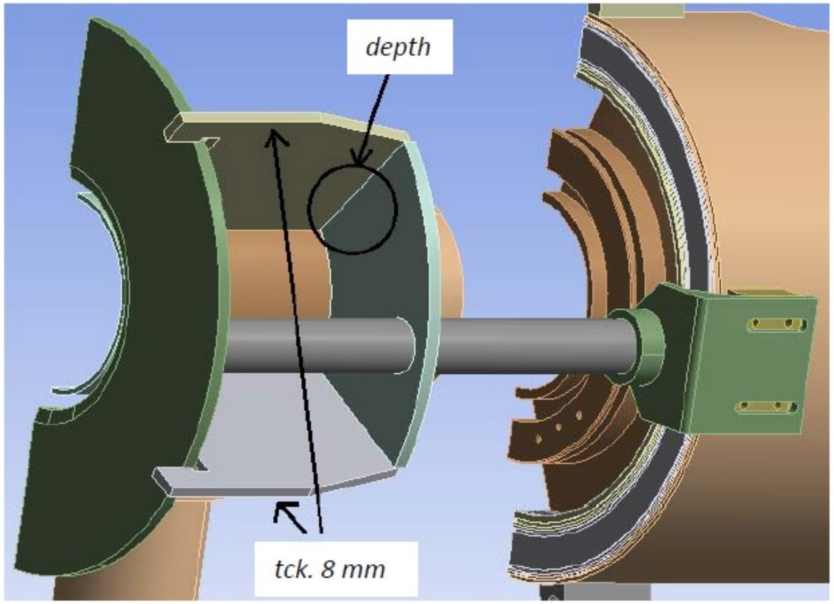


Stainless steel cylinders: length of 420 mm and diameter of 40 mm.

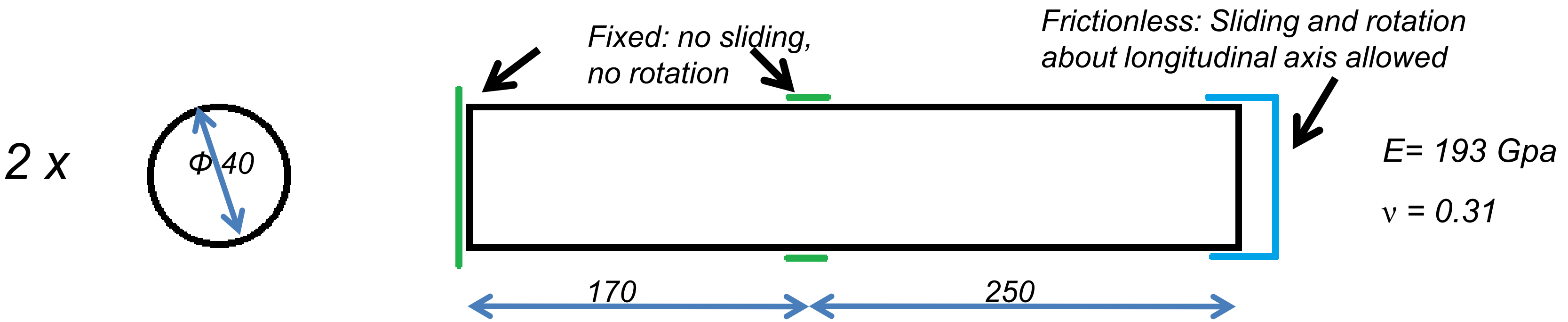
4. Inter-cavity sliding support

Size of stiffeners increased for better results:



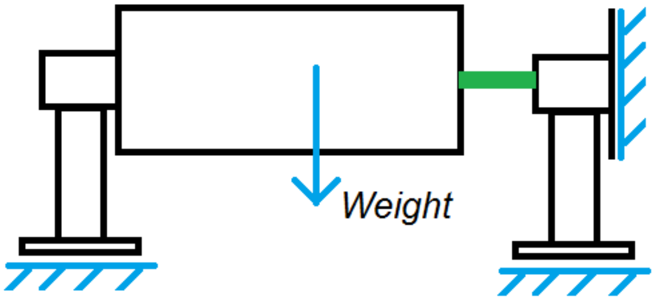


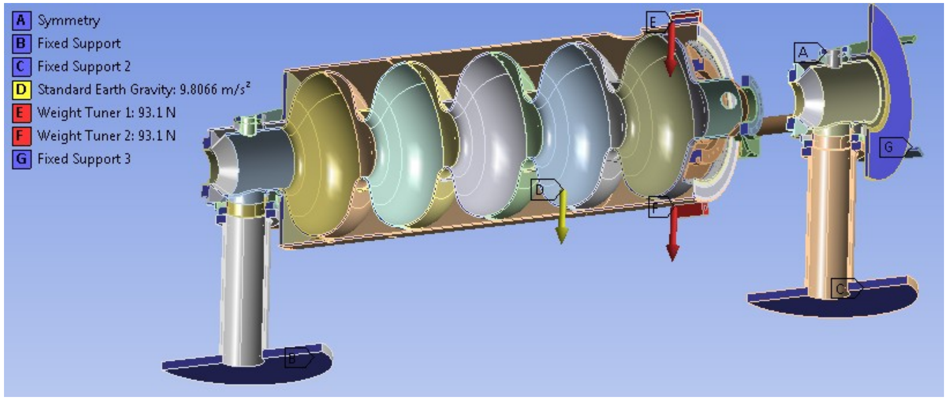
Inter cavity support's stiffness:



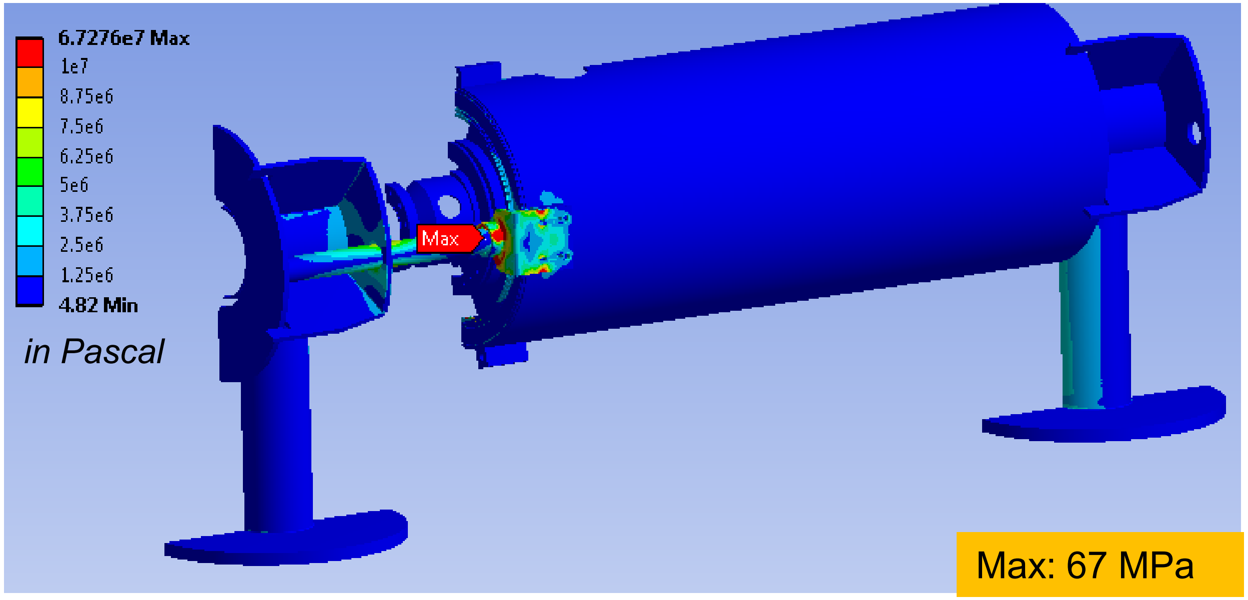
4. Inter-cavity sliding support

Analysis with one He vessel / cavity and two power couplers (double tube):



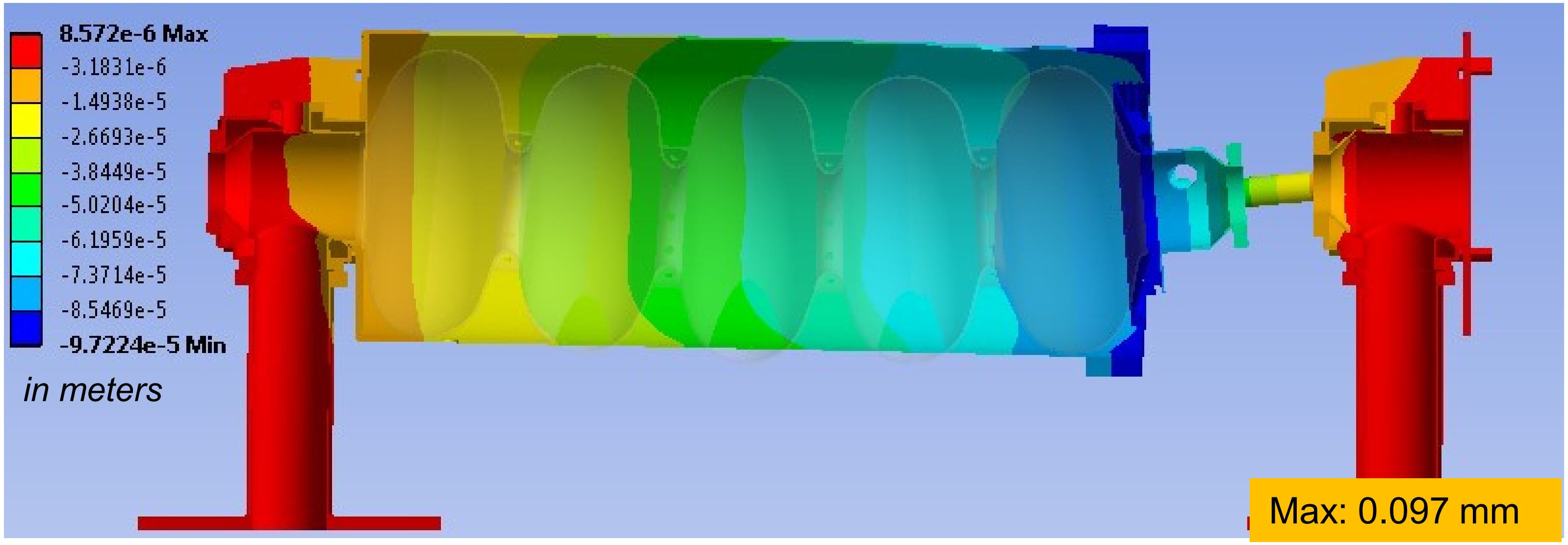


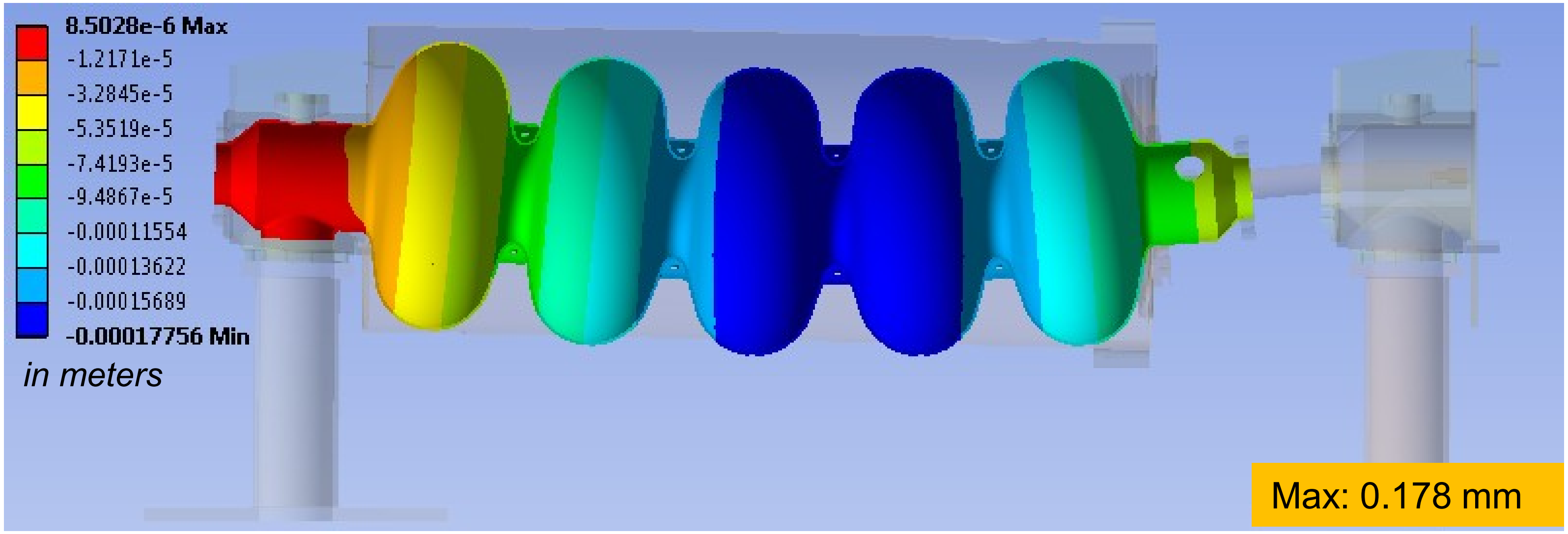
von Mises stress (Pa):



4. Inter-cavity sliding support

Vertical displacement (colour) [m]:

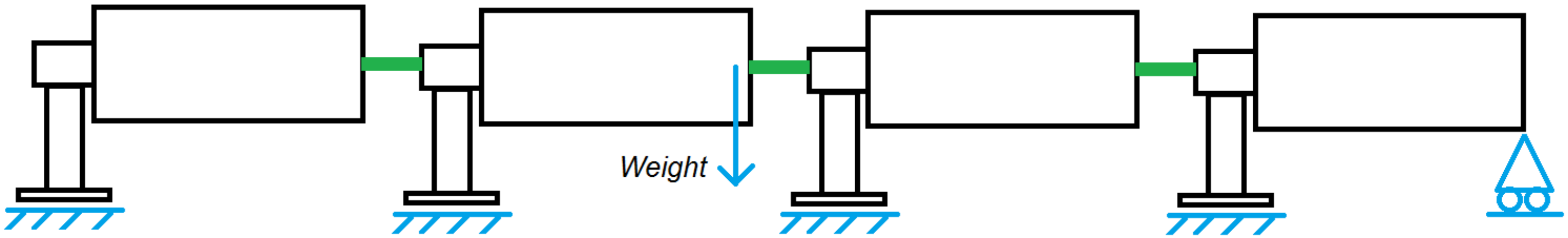


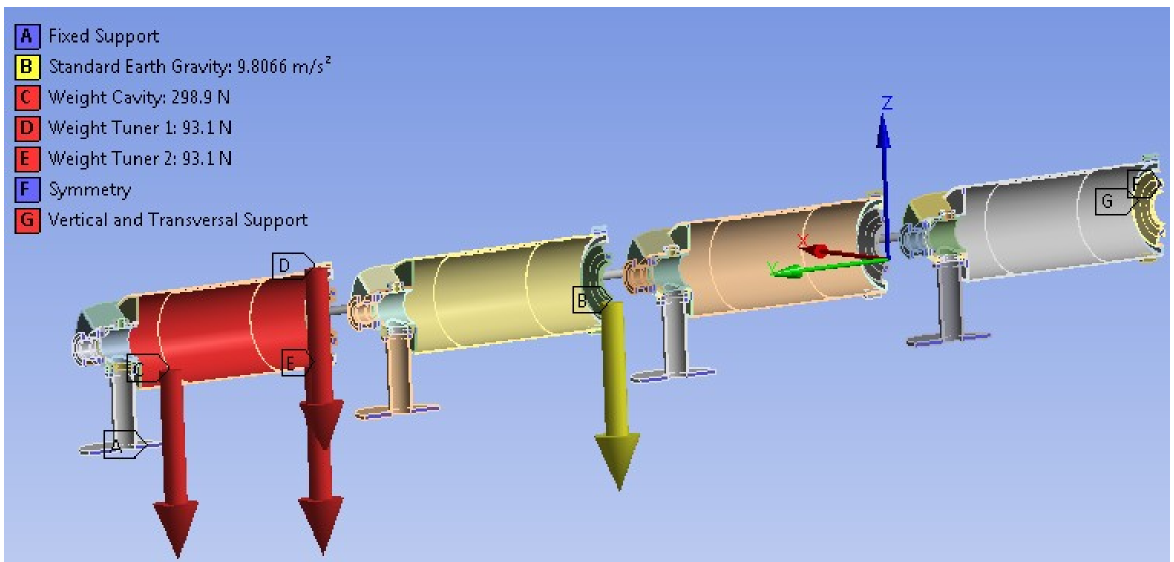


Body deformation amplified 300x

4. Inter-cavity sliding support

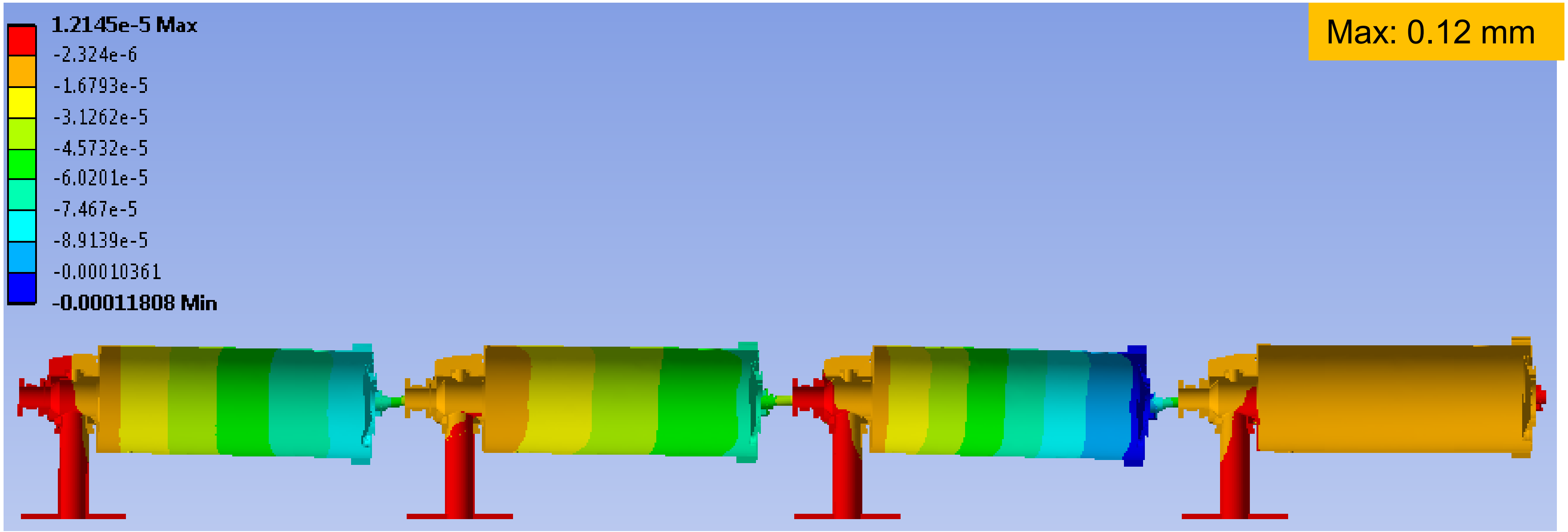
Analysis of string of 4 cavities:





4. Inter-cavity sliding support

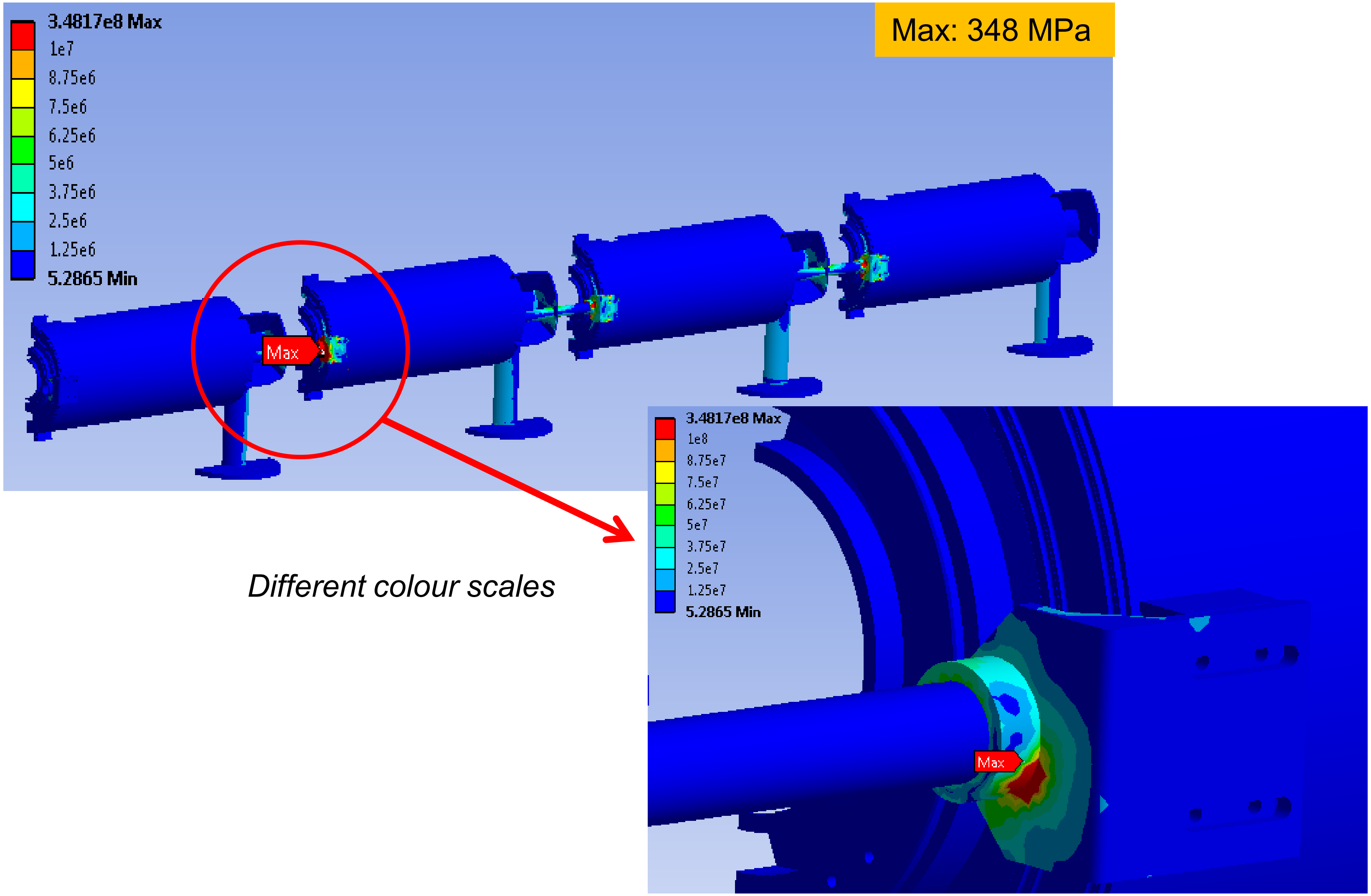
Vertical displacement (colour) [m]:



Body deformation amplified 300x

4. Inter-cavity sliding support

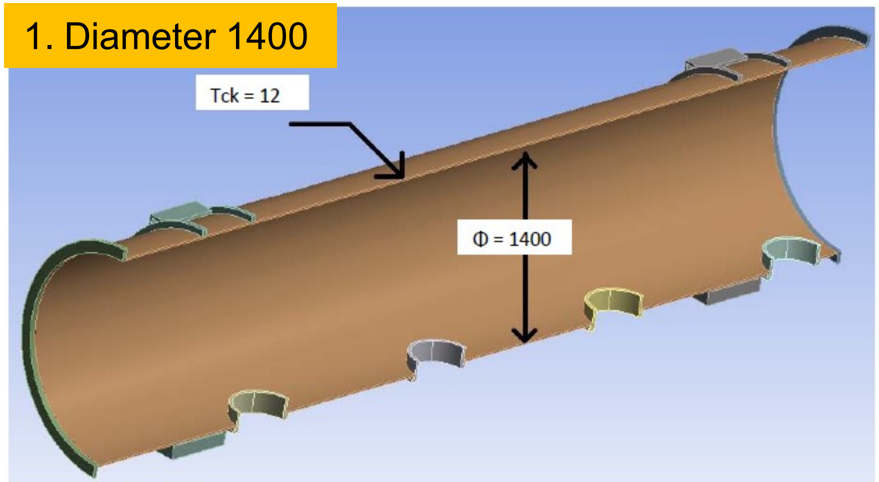
von Mises stress (Pa):

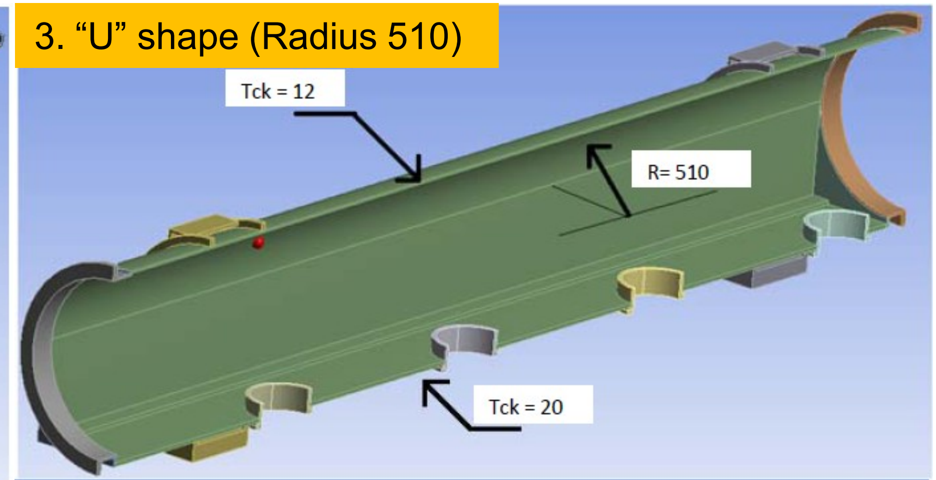


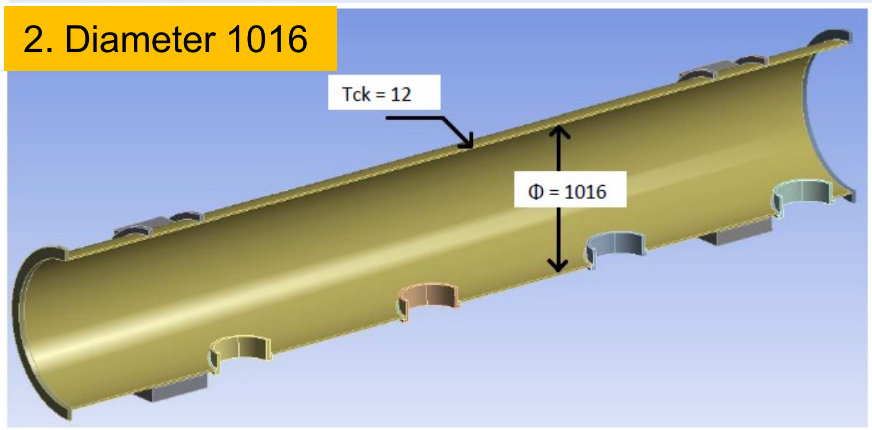
5. Vacuum vessel design

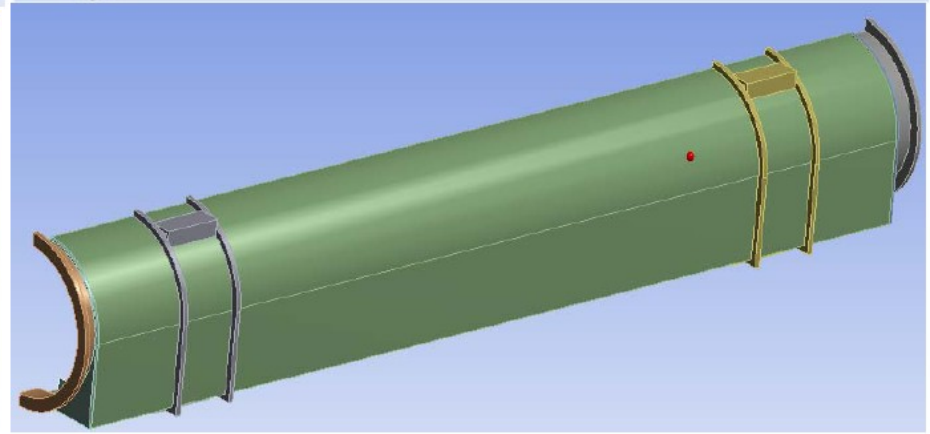
Three different vessels were modelled with the same thickness and supports. Two different shapes are analysed. All these calculations refer to conceptual designs.

A larger diameter may be a requirement for a circular vessel due to assembly.







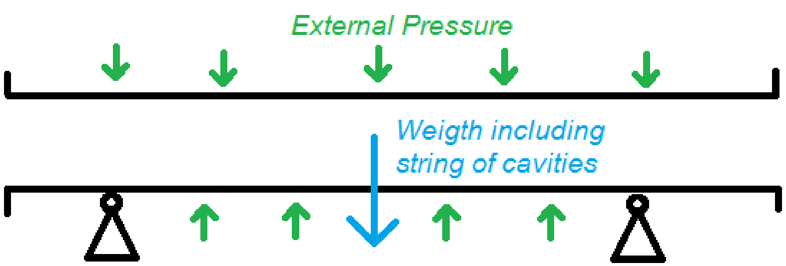


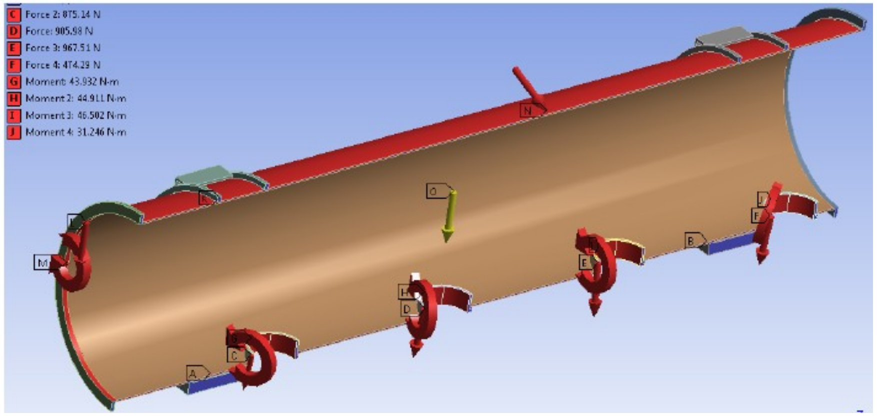
5. Vacuum vessel design

Different sets of loads were applied:

1. Weight loads: weight of vessel plus loads caused by weight of the string of cavities
2. Pressure loads: external pressure of 1 bar
3. Weight loads plus pressure

Weight loads plus pressure:





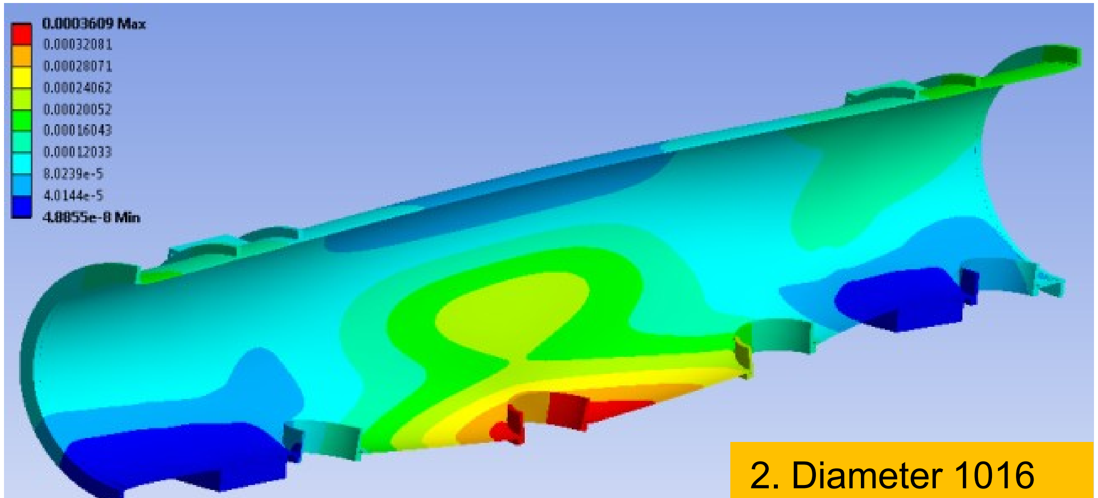
5. Vacuum vessel design

Results:

	Vessel	Loads		
		Weight	**Pressure**	**W + P**
Max. absolute displacement of vacuum vessel [mm]	1. “O” 1400	0.47	0.31	0.47
	2. “O” 1016	0.15	0.36	0.40
	3. “U” 1020	0.19	4.3	4.3
Max. vertical displacement of PC flanges [mm]	1. “O” 1400	0.061	0.31	0.36
	2. “O” 1016	0.062	0.35	0.39
	3. “U” 1020	0.19	0.52	0.44

5. Vacuum vessel design

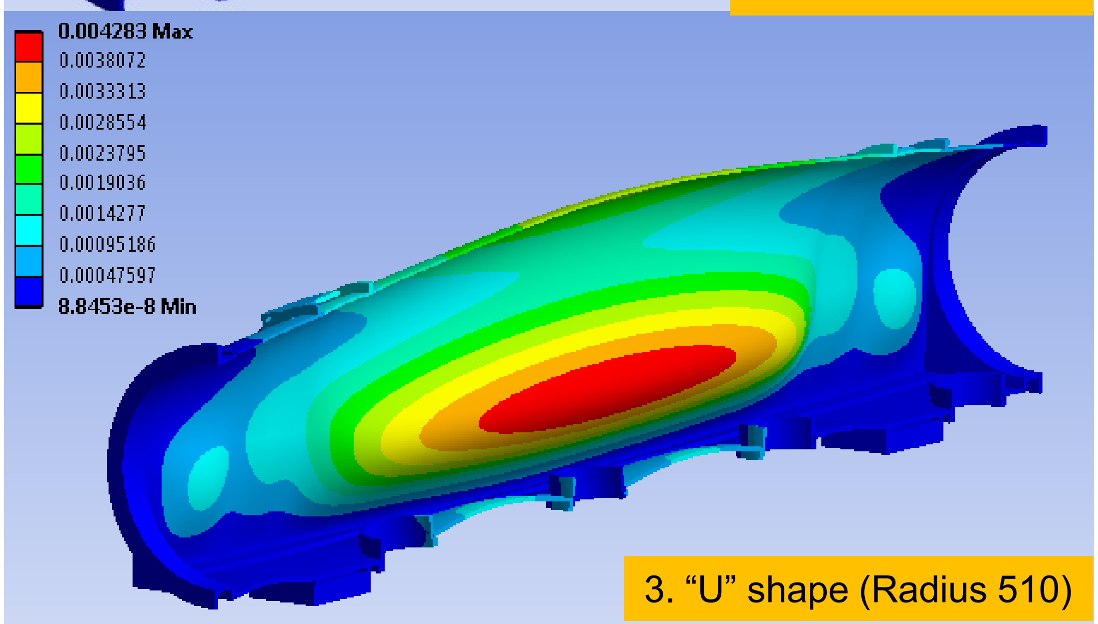
Results: Vertical displacement [m] under external pressure of 1 bar:



2. Diameter 1016

Max: 0.36 mm

Body deformation amplified 500x



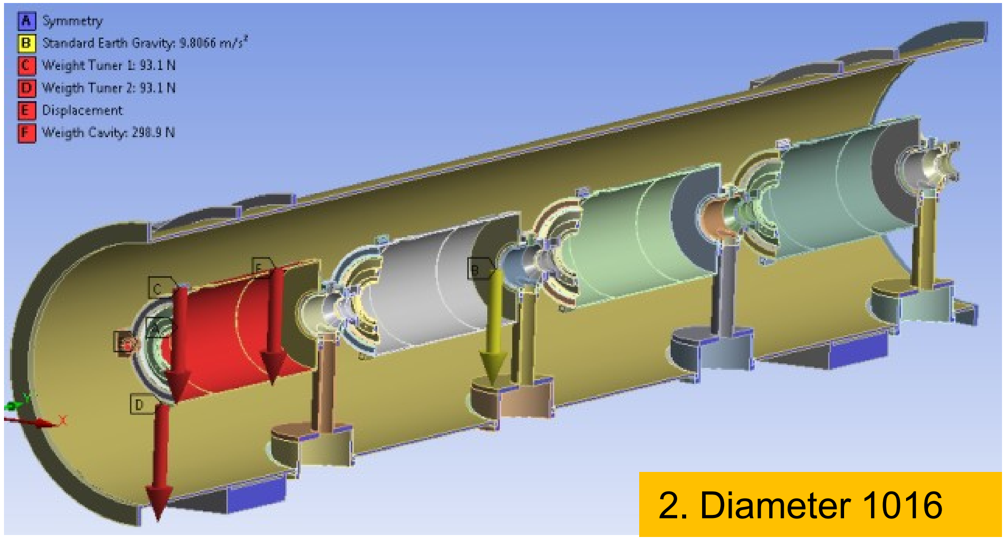
3. “U” shape (Radius 510)

Max: 4.3 mm

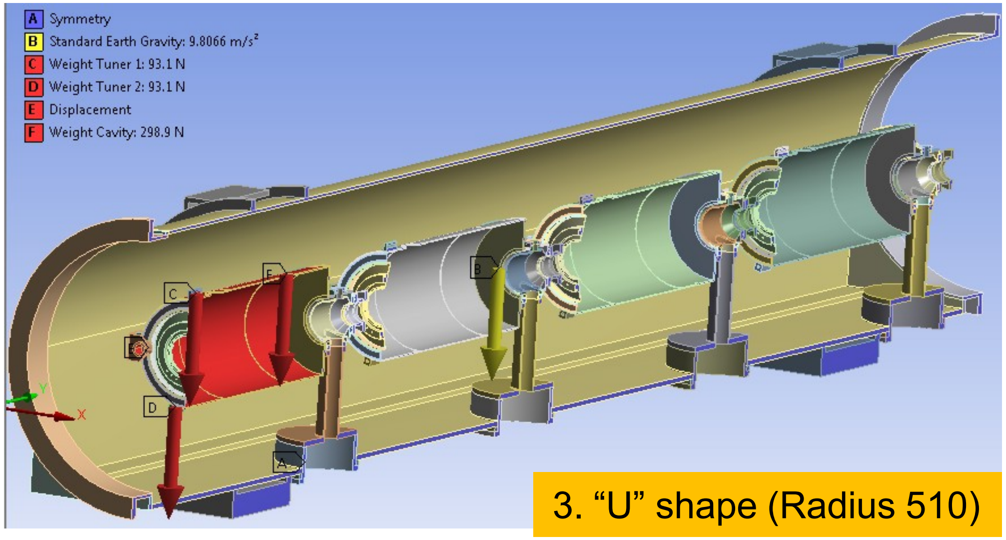
Body deformation amplified 100x

5. Vacuum vessel design

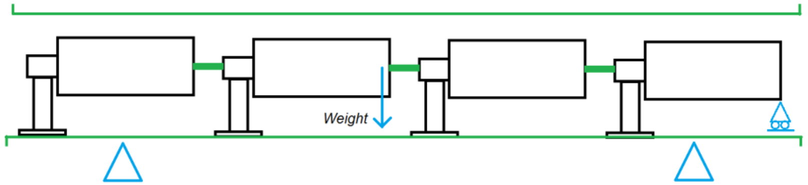
Analyses with string of cavities: smaller circular vessel and “U” shape vessel. Weight Load



2. Diameter 1016



3. “U” shape (Radius 510)



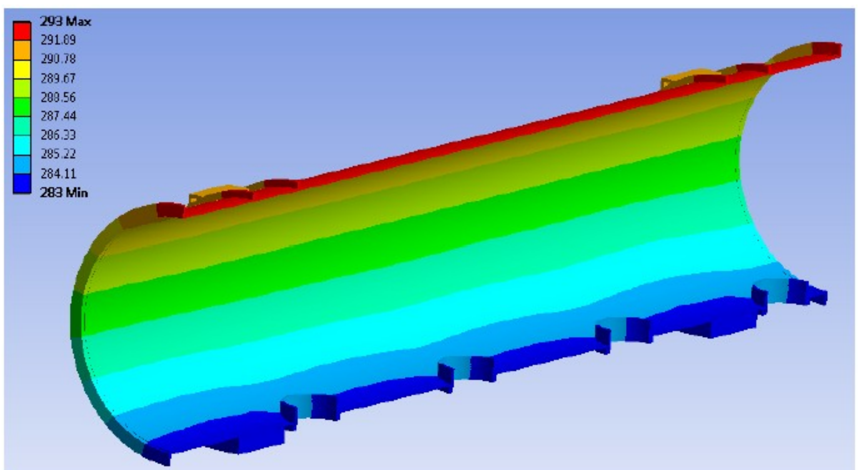
Positive but small influence of the stiffness of the string of cavities:

String of cavities	Vessel	Max. vertical displacement of PC flanges [mm]	Difference [%]
No	O	0.062	-
No	U	0.19	-
Yes	O	0.058	7.0
Yes	U	0.17	12.7

5. Vacuum vessel design

Thermal gradient: 10 K difference between top and bottom of vessel (tentative value – a full thermal model should be made, including active cooling of couplers).

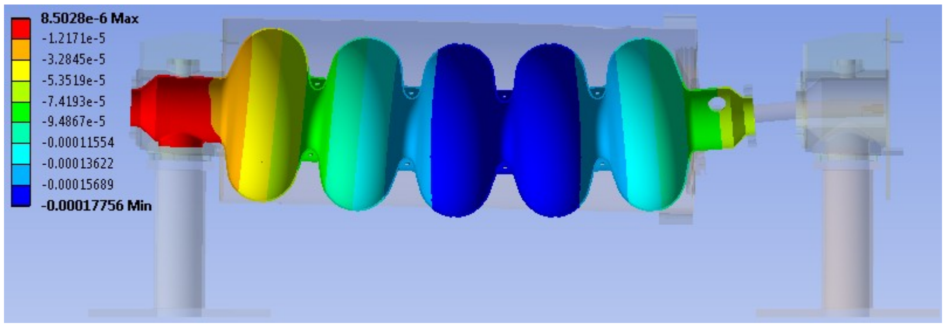
Thermal gradient:

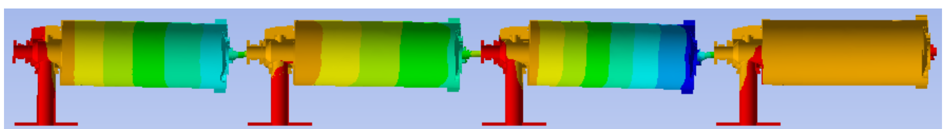


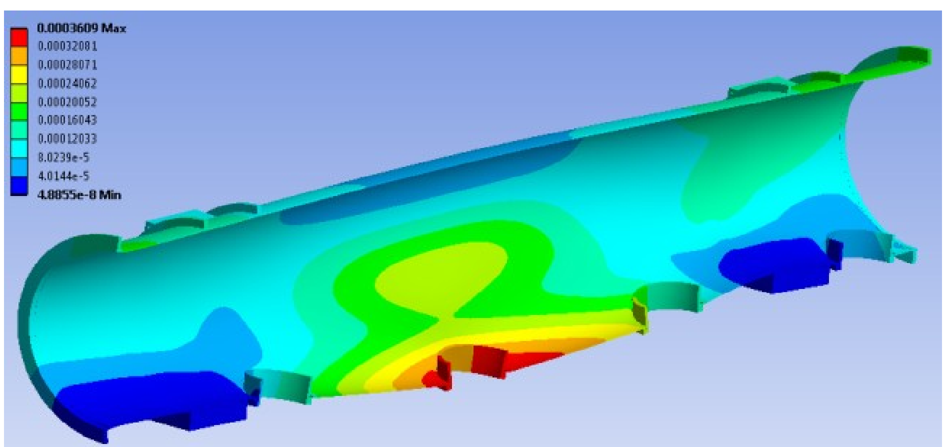
	Vessel	Displacement
Max. absolute displacement of vacuum vessel [mm]	1. “O” 1400	0.73
	2. “O” 1016	0.55
	3. “U” 1020	0.50
Max. vertical displacement of PC flanges [mm]	1. “O” 1400	0.51
	2. “O” 1016	0.40
	3. “U” 1020	0.40

5. Vacuum vessel design

Resume of results and estimation of accumulated deflections



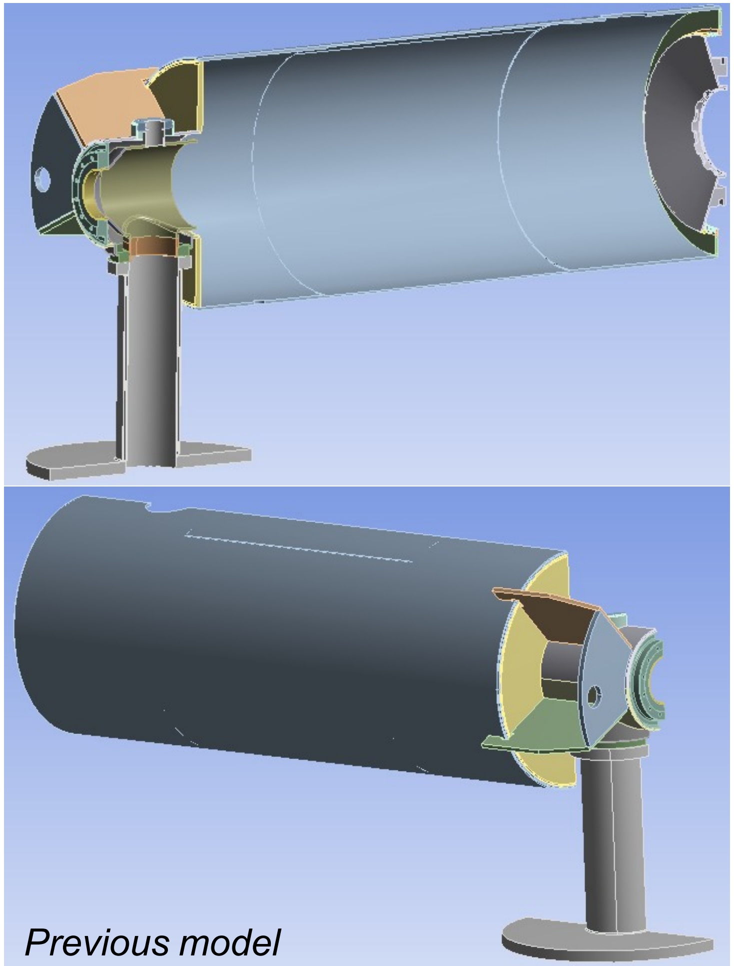




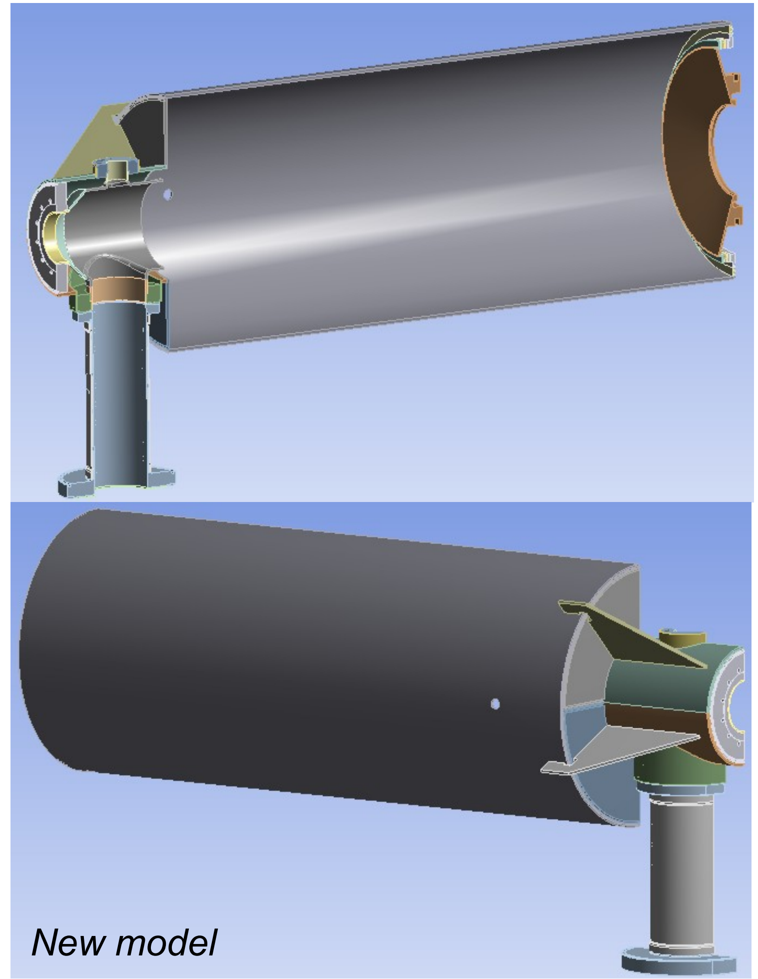
	Vertical displacement [mm]	Accumulated vertical displacement of cavity [mm]
Cavity sag (self weight)	0.13 (Center of cavity)	
He Vessel (string of cavities - weight)	0.12 (Extremity of He Vessel)	0.19
Circular vacuum vessel 1016 mm (weight and pressure)	0.36 (PC flange)	0.55
Circular vacuum vessel 1400 mm (weight and pressure)	0.39 (PC flange)	0.58

6. Recent models – comparison

New models of the vacuum vessel and power coupler were compared to previous models.



Previous model

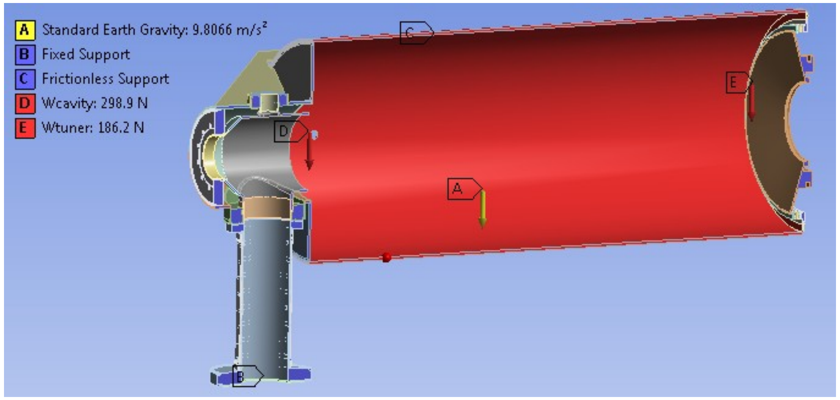


New model

Main differences: thickness of the helium vessel, not constant in the first case (3 and 5 mm) and constant in the second (5 mm), thickness of the outer and inner walls of the power coupler, as well as the space between them (respectively 1.5, 2 and 4.5 mm for the older version and 2, 1.5 and 1 mm for the new version).

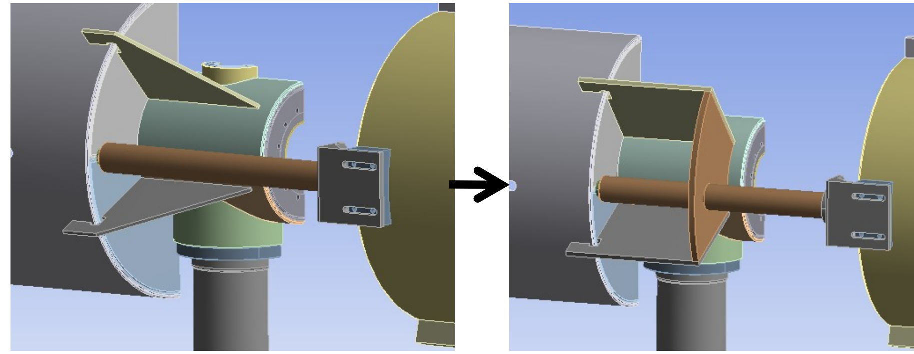
6. Recent models – comparison

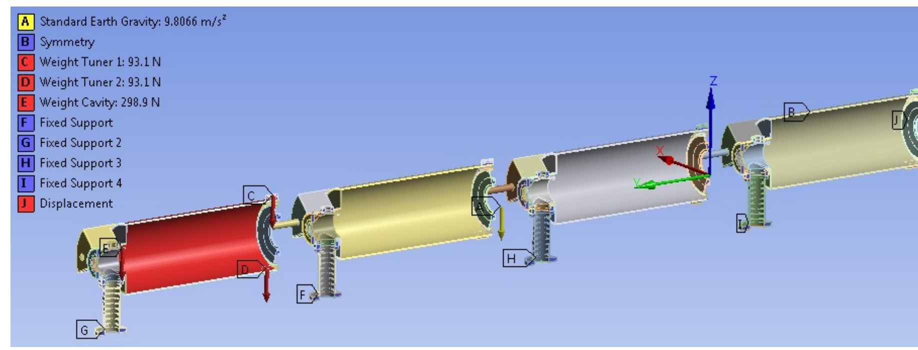
Analyses single cavity



Model	Maximum deflection (mm)
Older	2.3
Older; altered reinforcements	2.1
New; altered reinforcements	1.5

Analyses string of four cavities cavity

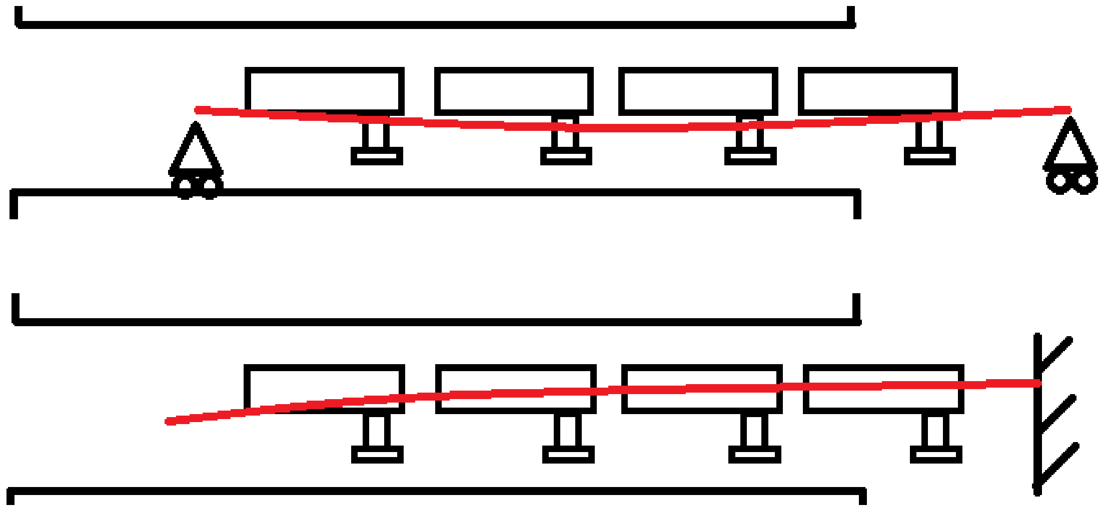




Model	Maximum deflection (mm)
Older; altered reinforcements	0.12
New, original reinforcements	0.66
New, altered reinforcements	0.091

7. Assembly tooling – Required stiffness

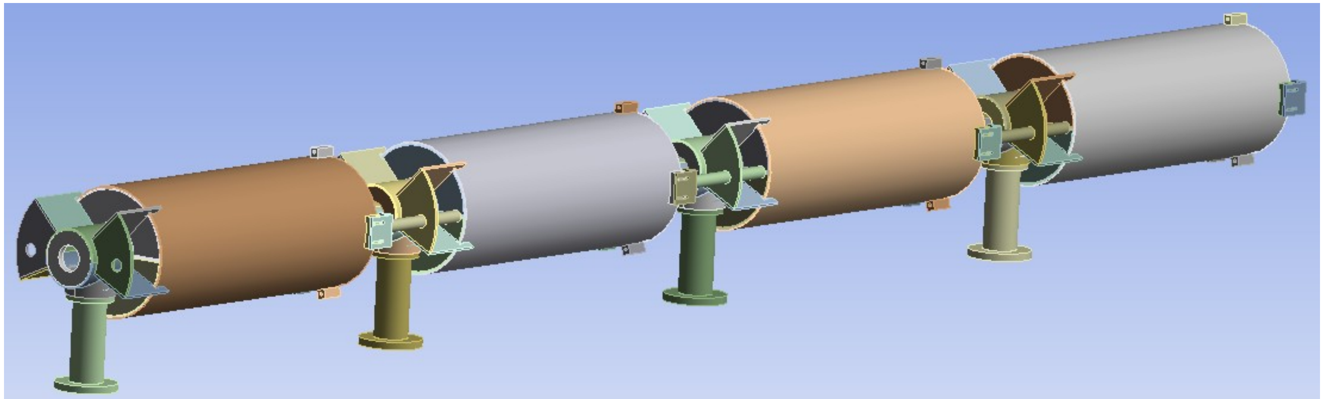
Different support scenarios were considered. FE calculations including the string of cavities were performed. Analytical calculations were carried out considering that the support system is comparable to a beam.



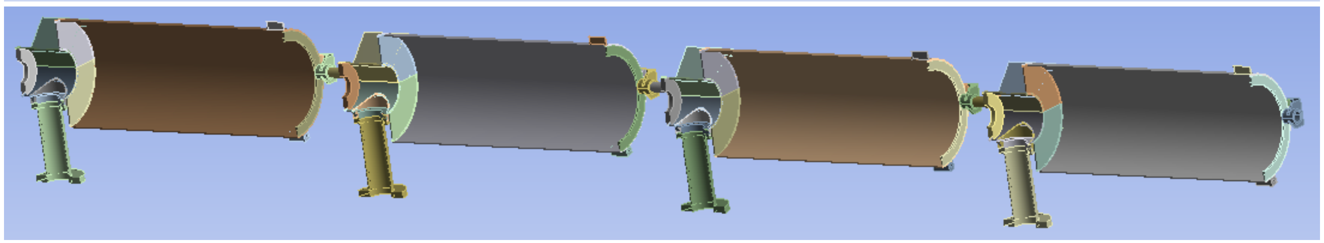
The length of the beam is 6.8 m for the 4 cavities test cryostat, and the double for the 8 cavities cryomodule.

7. Assembly tooling – Required stiffness

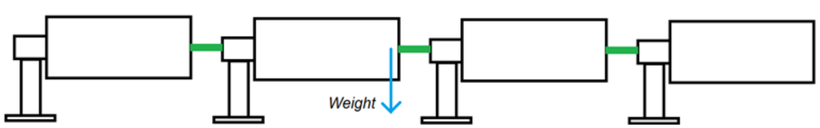
FE analyses of the string of cavities, simplified model and loads:



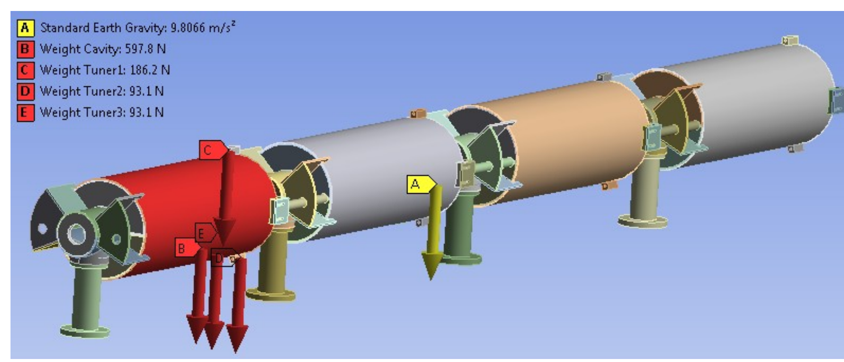
Global view



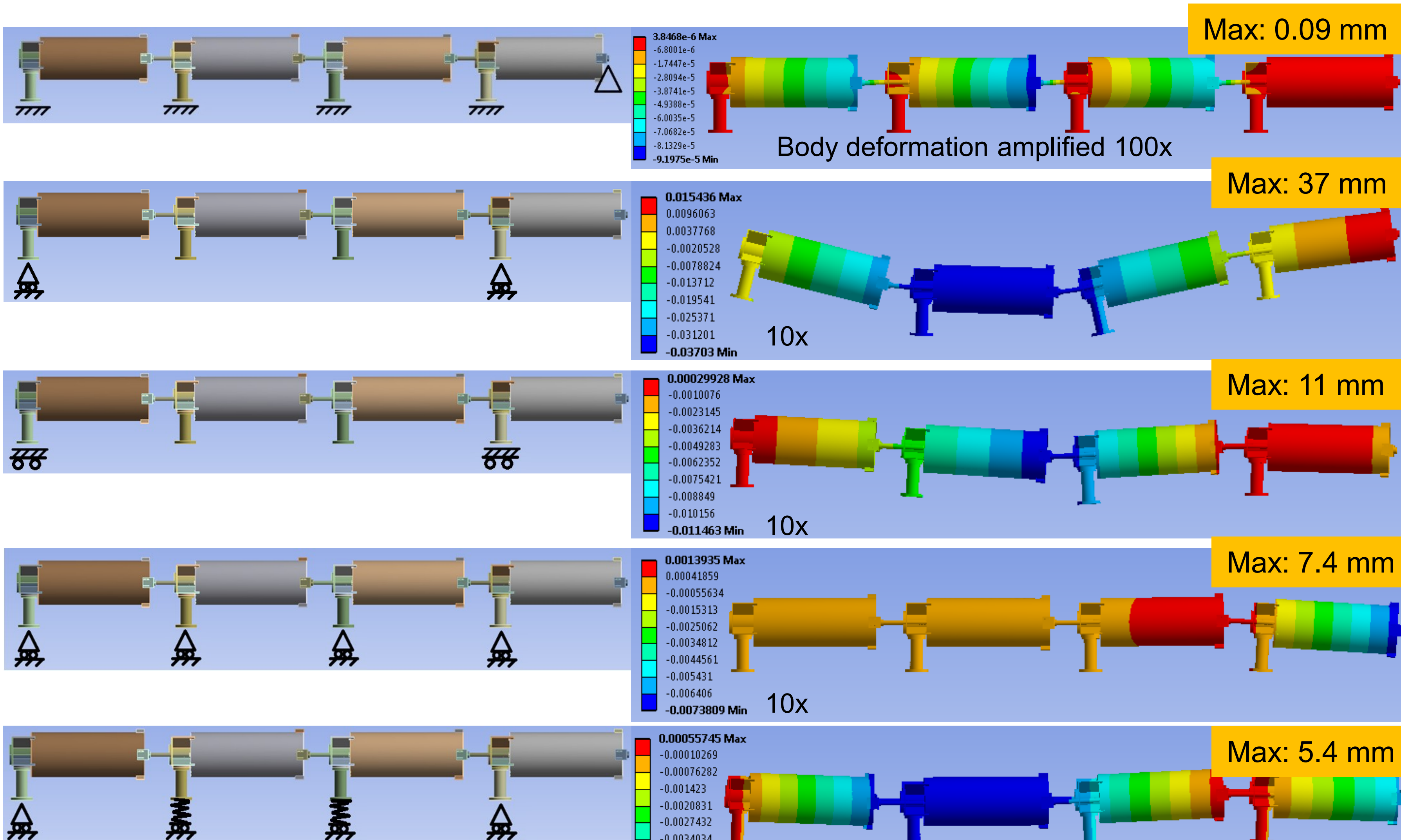
Section plane view



Fixed inter cavity support (instead of sliding)



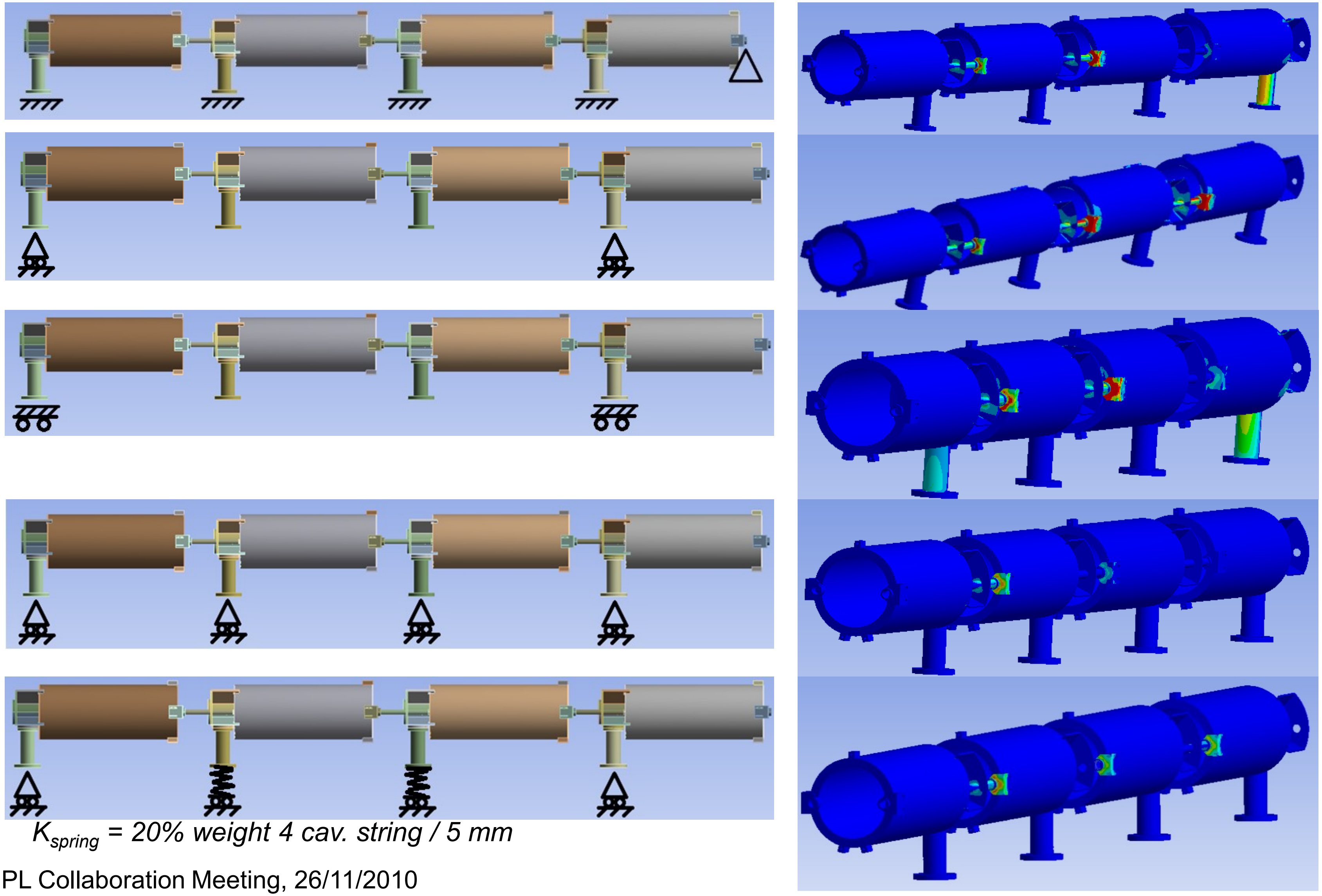
7. Assembly tooling – Required stiffness



K_{spring} = 20% weight 4 cav. string / 5 mm

7. Assembly tooling – Required stiffness

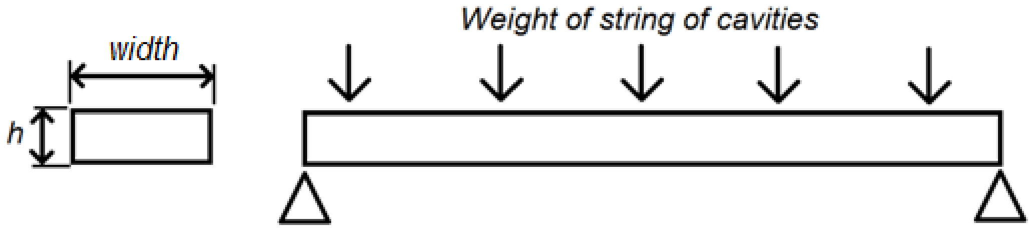
In red: von Mises stress values higher than half of the yield strength of stainless steel (~200 MPa):



K_{spring} = 20% weight 4 cav. string / 5 mm

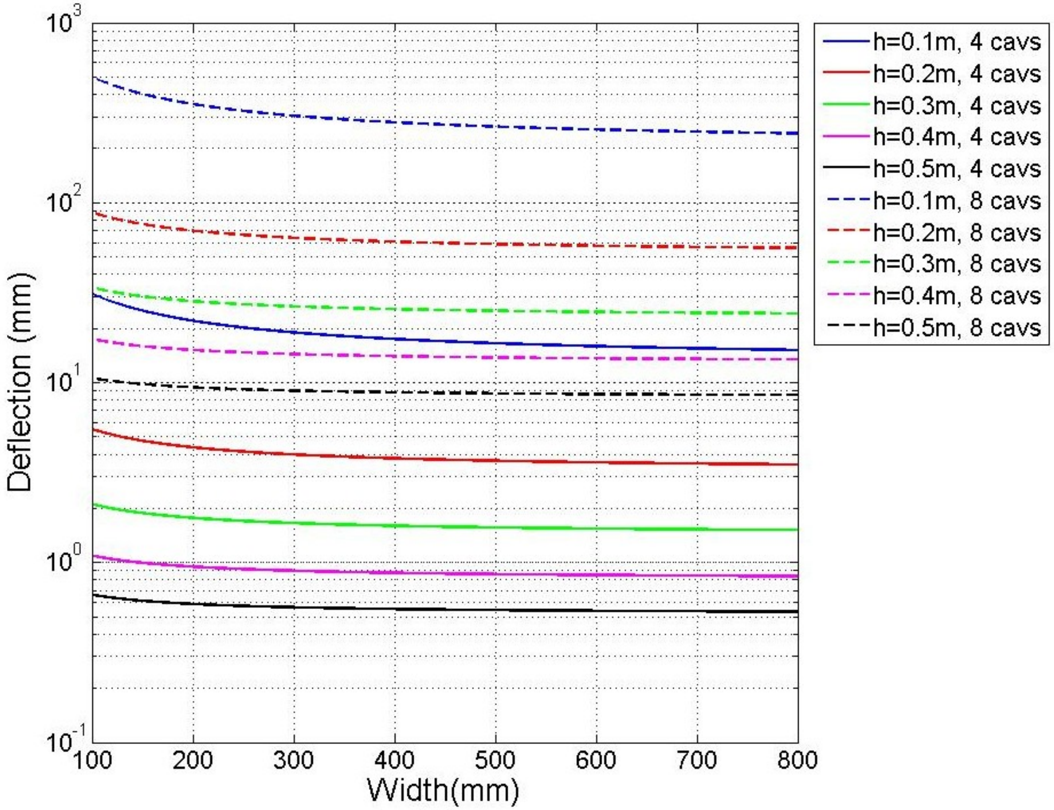
7. Assembly tooling – Required stiffness

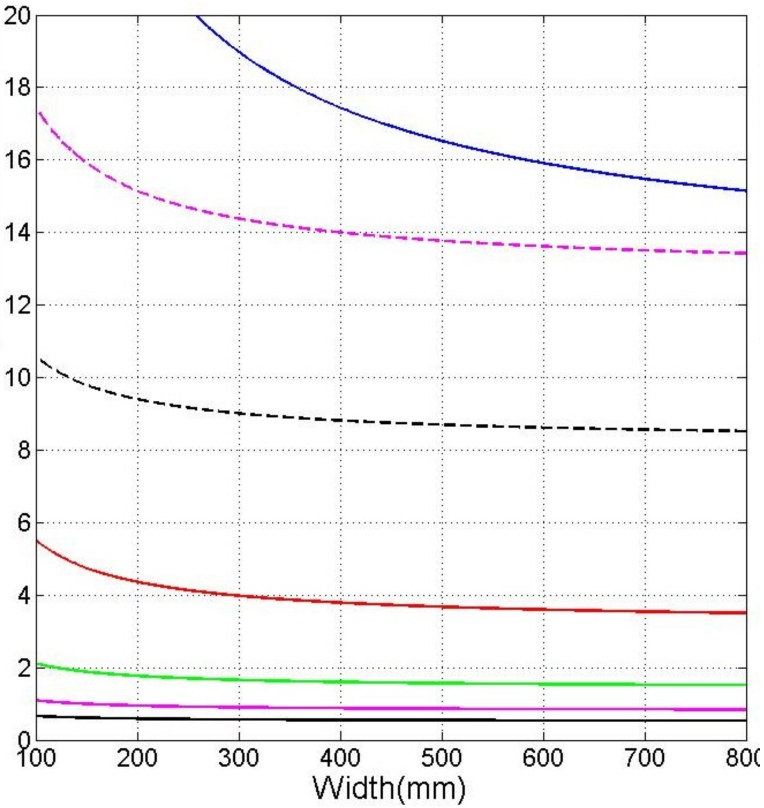
Support: Analytical calculation



Loads: Weight of string of cavities and support

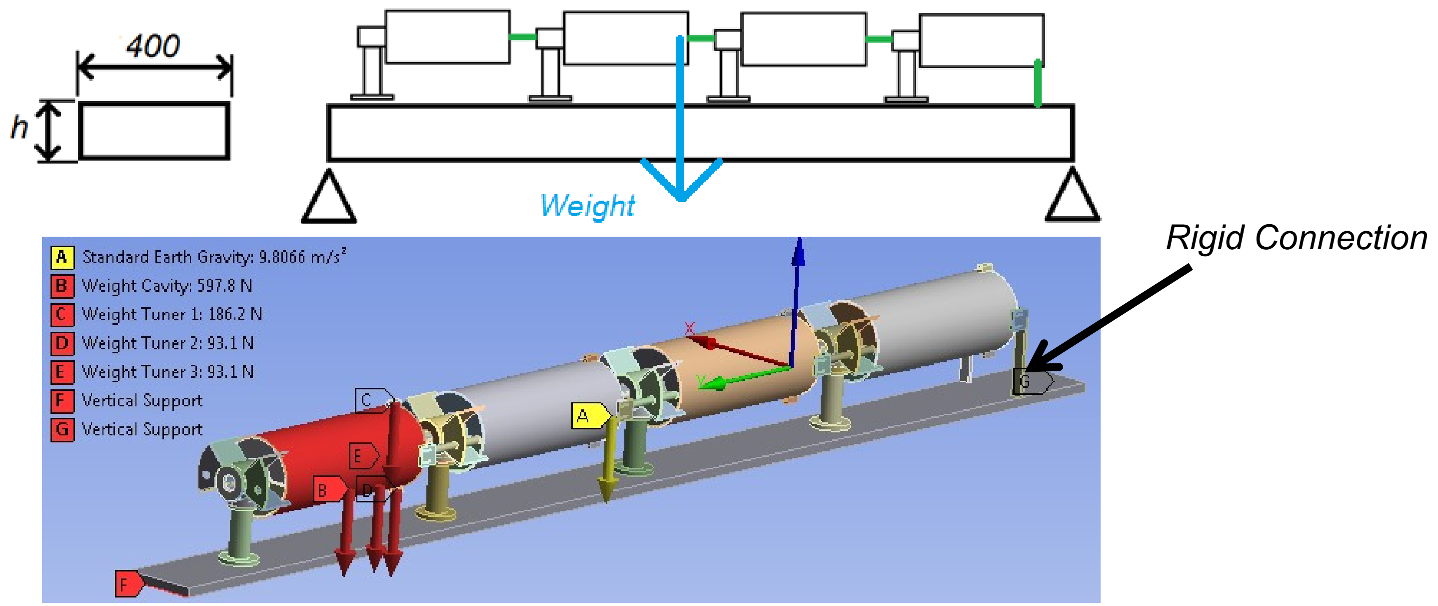
Material: Structural steel: *ρ=7850 kg/m³; E=2e¹¹ Pa*





7. Assembly tooling – Required stiffness

Support: Analyses with the string of cavities; different sizes

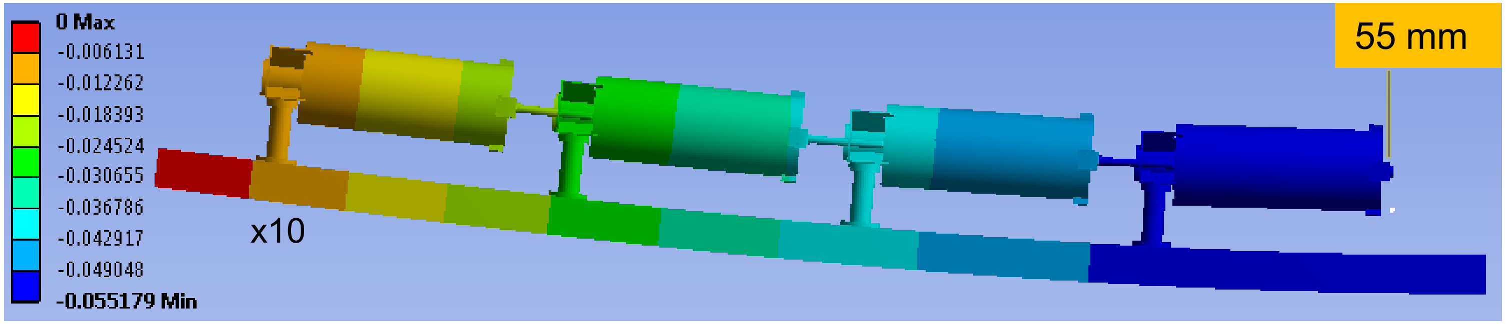


Support height (h) [mm]	Maximum deflection Support [mm]	Maximum deflection String [mm]	Max stress Support [MPa]
50	10	10	157
100	8.1	8.3	134
200	3.3	3.4	17

7. Assembly tooling – Required stiffness

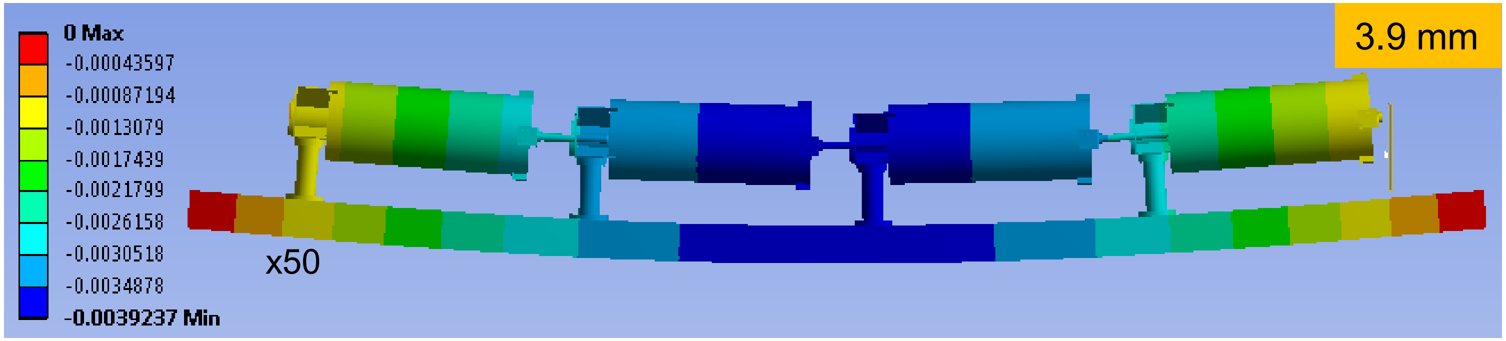
Comparison: string of 8 cavities (symmetry applied) – 400x200 support

Vertical displacement [m]



Comparison: sliding inter-cavity support – 400x200 support

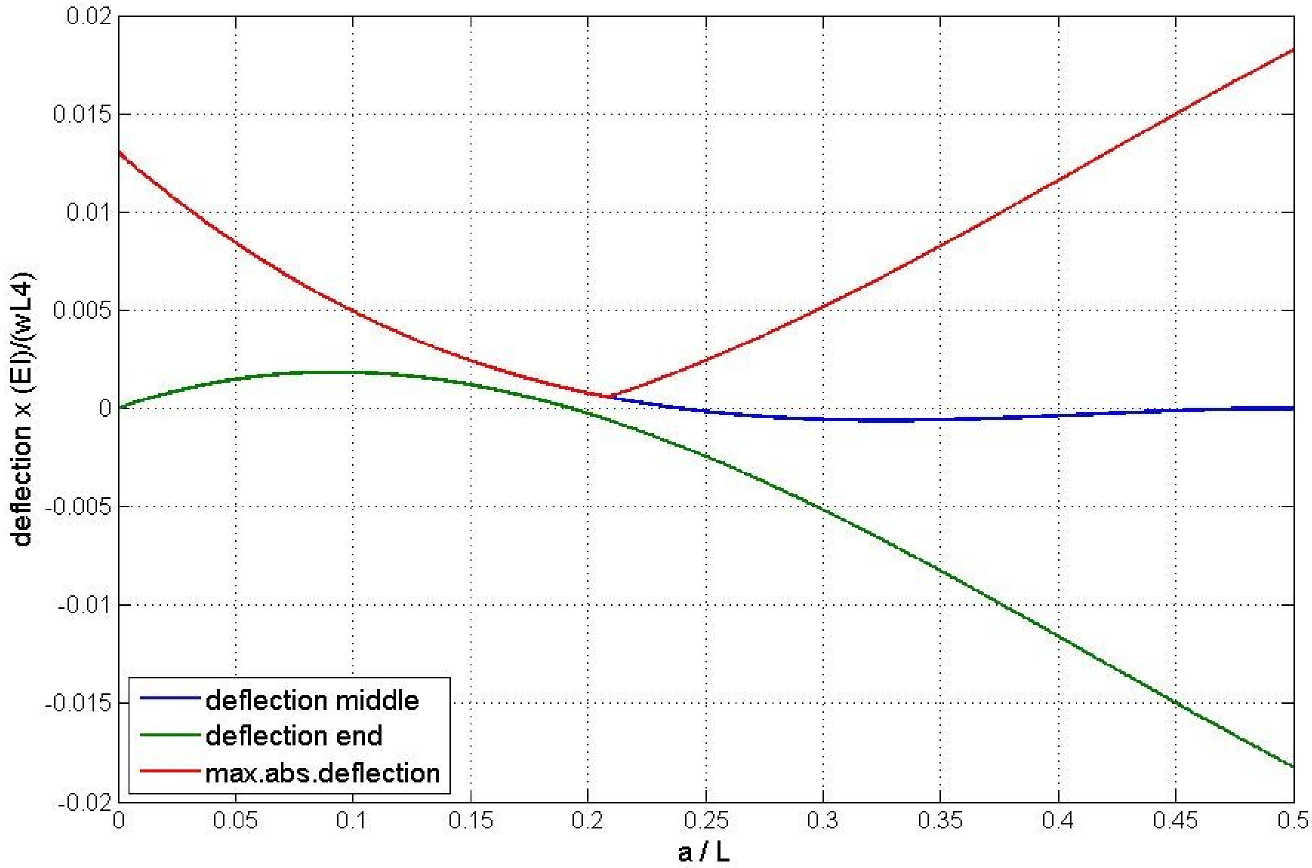
Vertical displacement [m]



Spare Slides

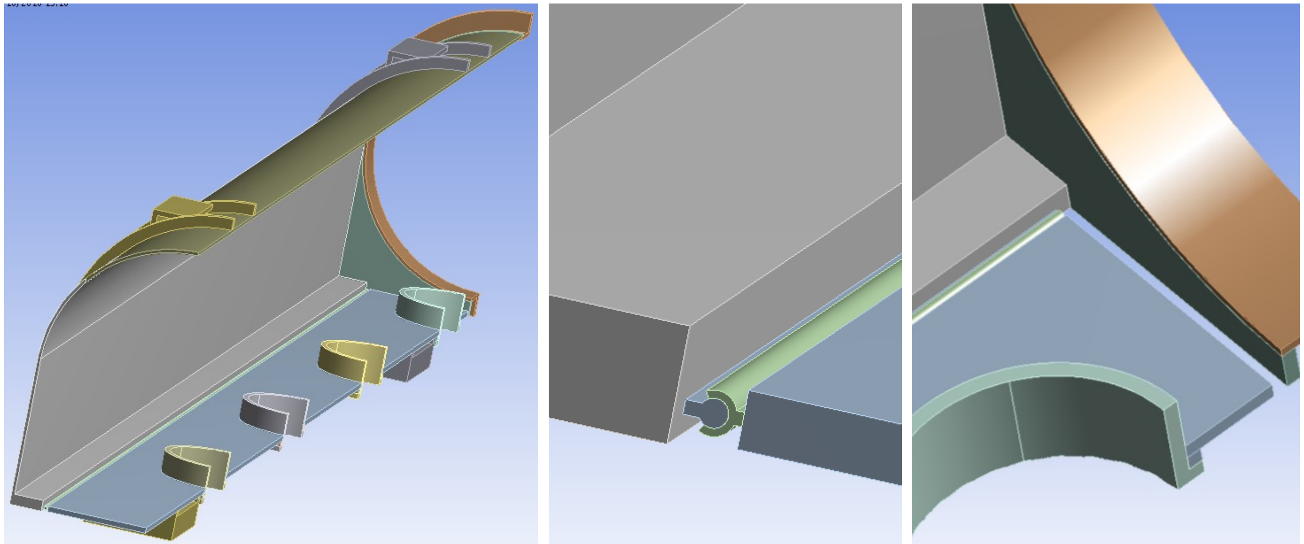
Supporting system: Position of 2 supports

Definition of the supports' position

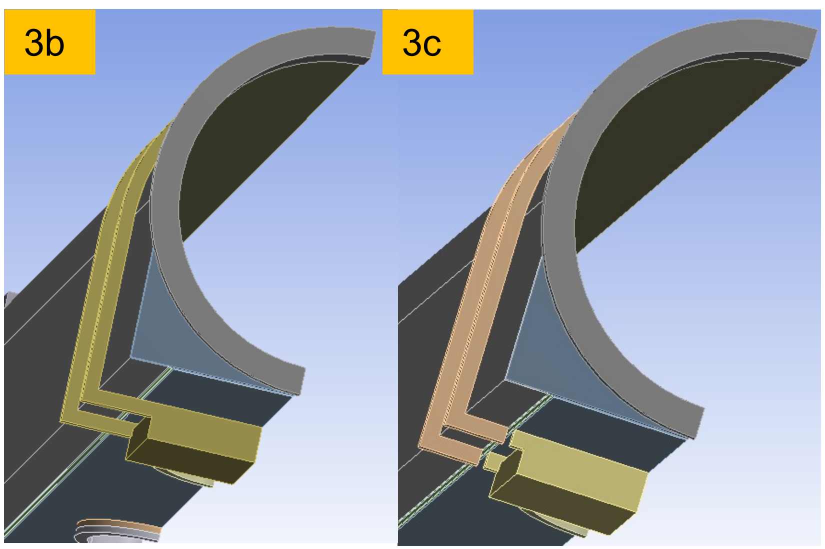


The position of the supports which minimizes the maximum deflection is *a / L*=0.2082

Non continuous "U" shape vessel



Two Alternatives: Reinforcement integrity (3b) vs. Free rotation (3c)



	Vessel	Loads	
		Weight	Pressure
Max. vertical displacement of PC flanges [mm]	3 (continuous)	0.19	0.52
	3b	0.036	0.65
	3c	0.039	0.78