COMPARISON BETWEEN MECHANICAL MEASUREMENTS AND FEA RESULTS OF THE D2 SHORT MODEL MBRDS1c

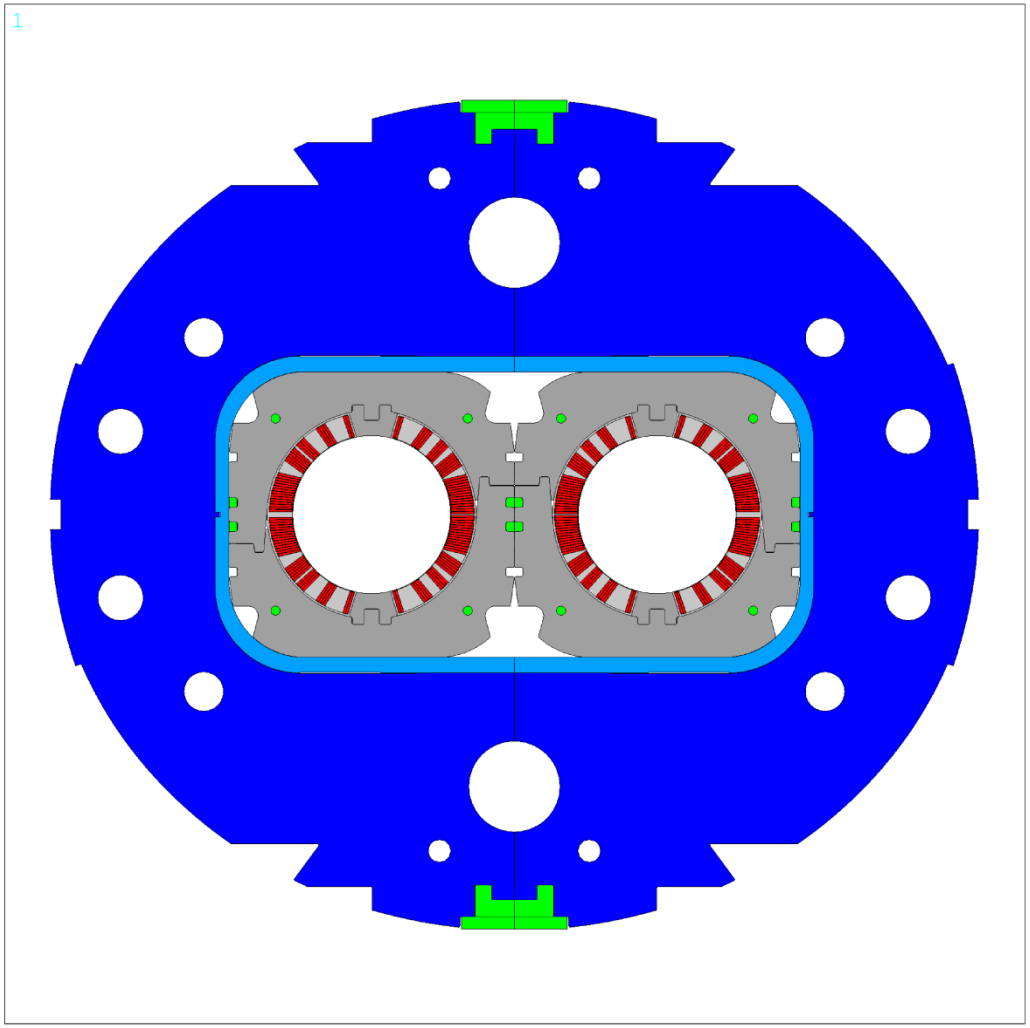
S. Farinon, A. Bersani, B. Caiffi, P. Fabbricatore, F. Levi, A. Pampaloni
A. Foussat, L.Bianchi, M. Guinchard

Sept. 2nd 2020

S.Farinon (INFN-Sezione di Genova)

FEA 2D MODEL

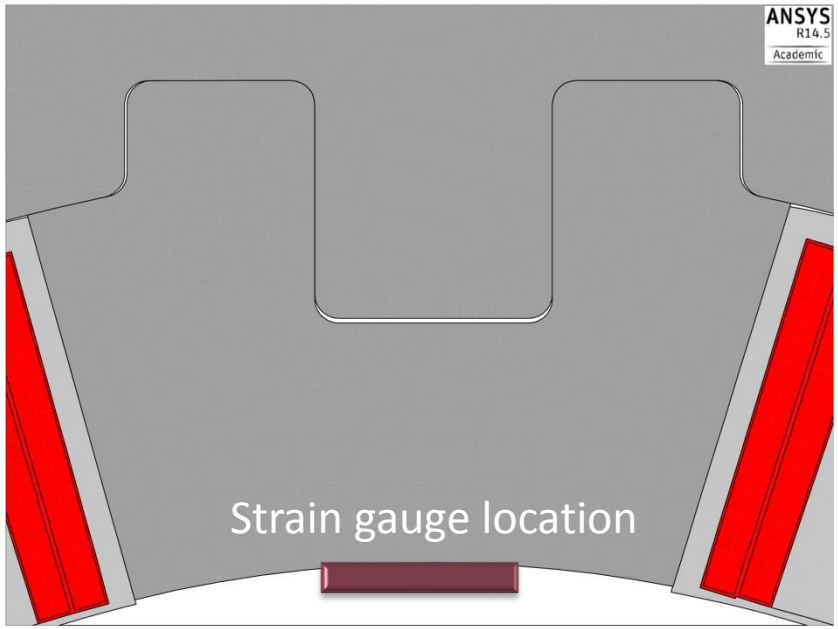
FEA 2D model



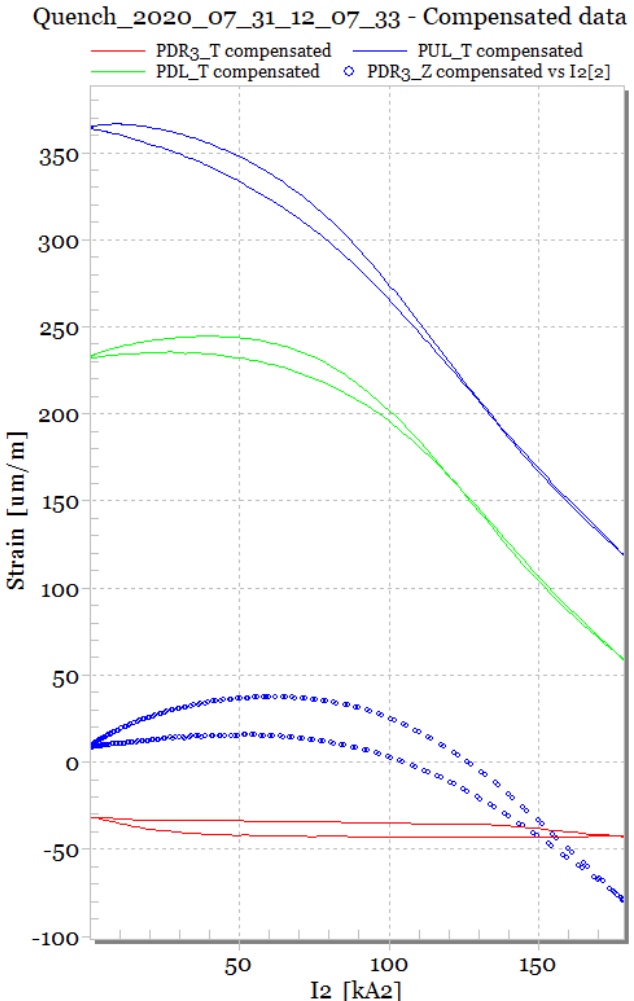
- The 2D model is built piling up turns from the pole towards the midplane, simulating real winding
- The dimensions of the turns are determined previously simulating the stack tests
- Following operations are: collaring, insertion of the Al sleeves, yoking, welding of the outer shell, cool-down, energization up to ultimate current

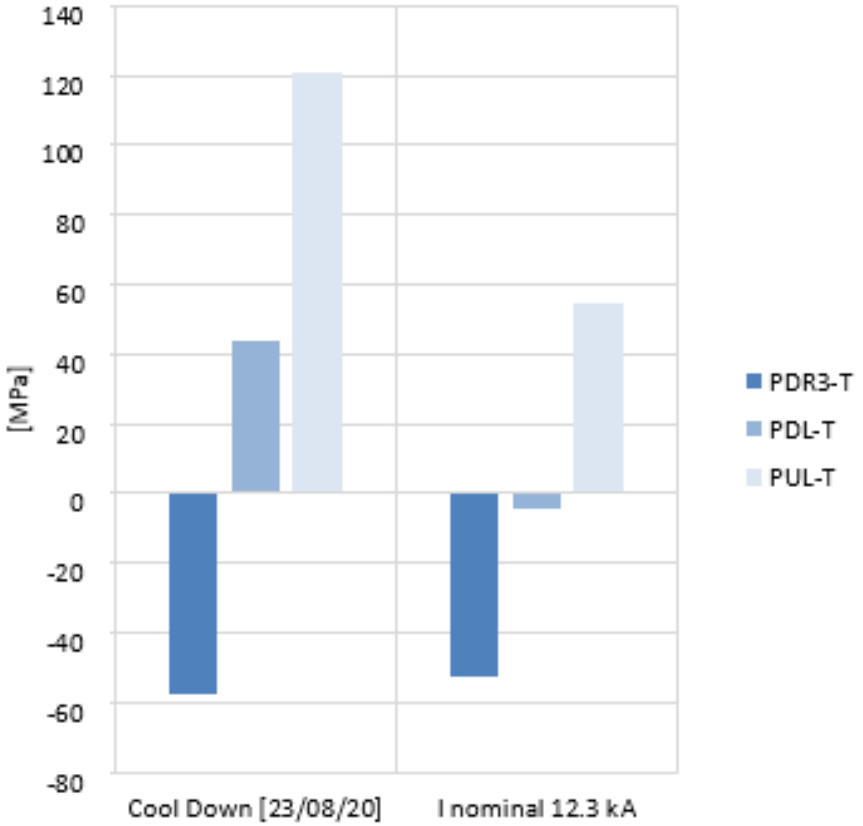
Pole unloading

- Unfortunately, only few strain-gauges survived
- However, it emerged quite clearly that the pole unloading was of the order of 40 MPa



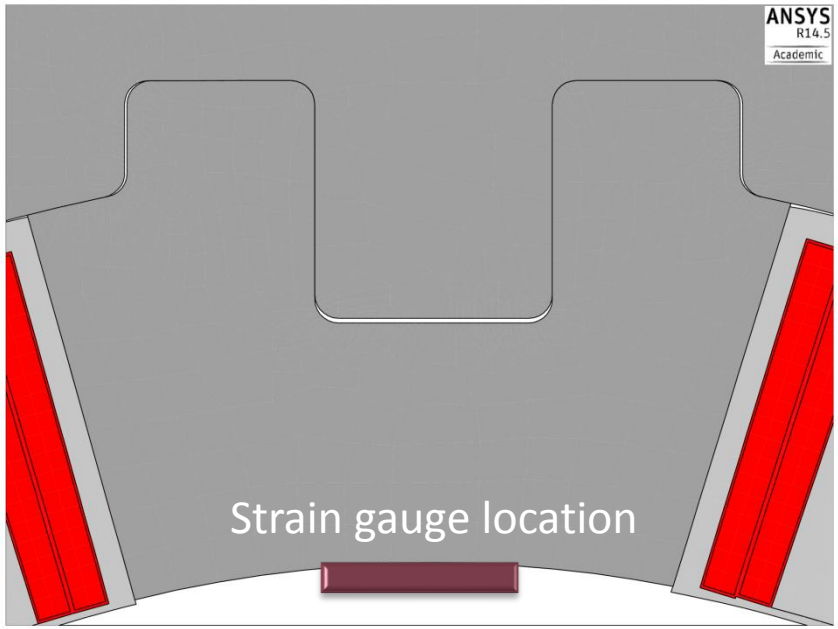
Pole unloading measurements





Pole unloading

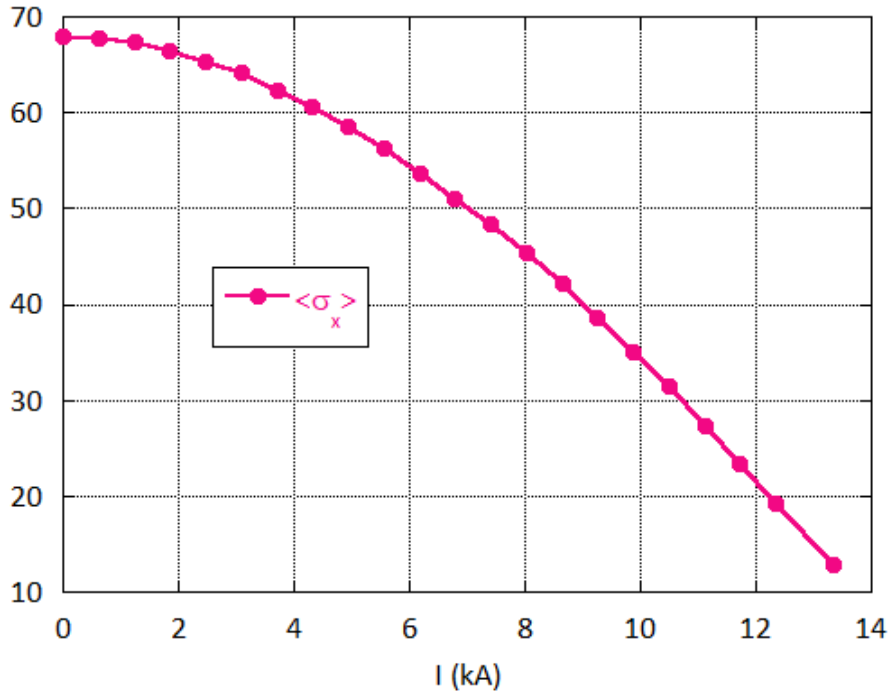
- Unfortunately, only few strain-gauges survived
- However, it emerged quite clearly that the pole unloading was of the order of 40 MPa

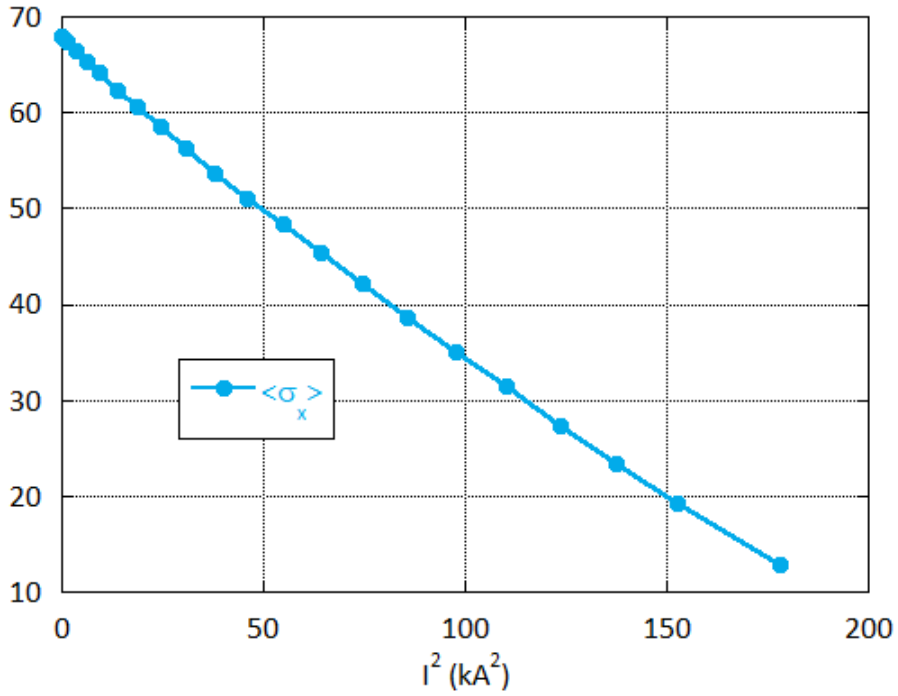


- To evaluate this unloading, we compute the average stress in the x direction in the elements belonging to the pole and adjacent to the strain gauge position

Pole unloading comparison

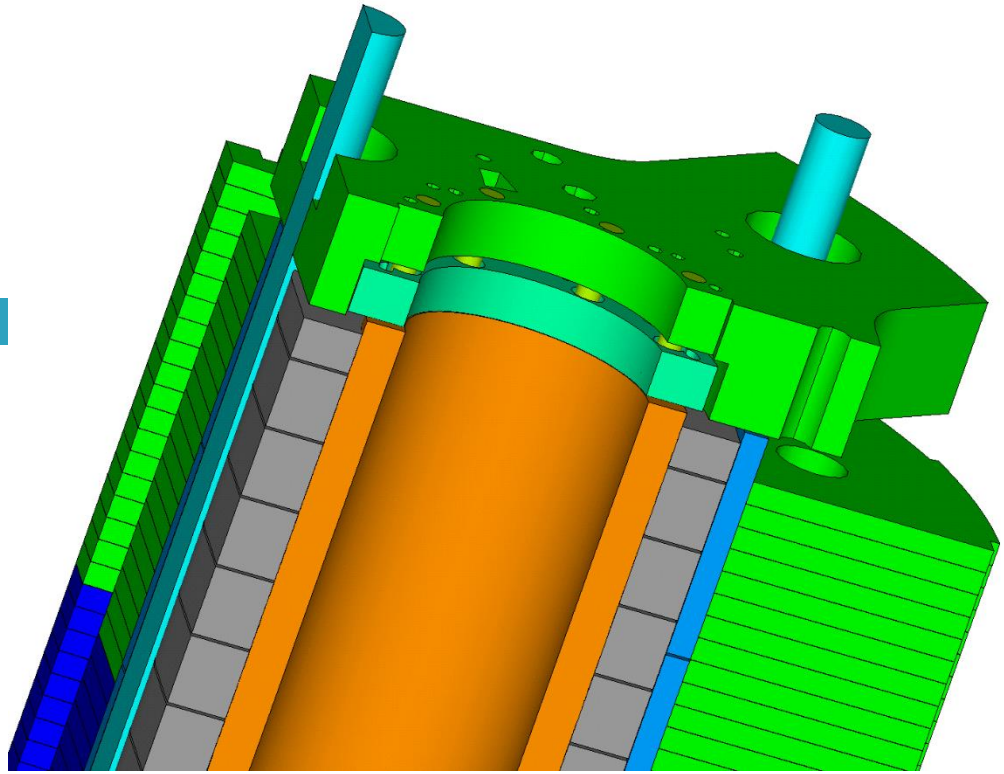
- The calculated unloading between cool-down and nominal current is 48.6 MPa

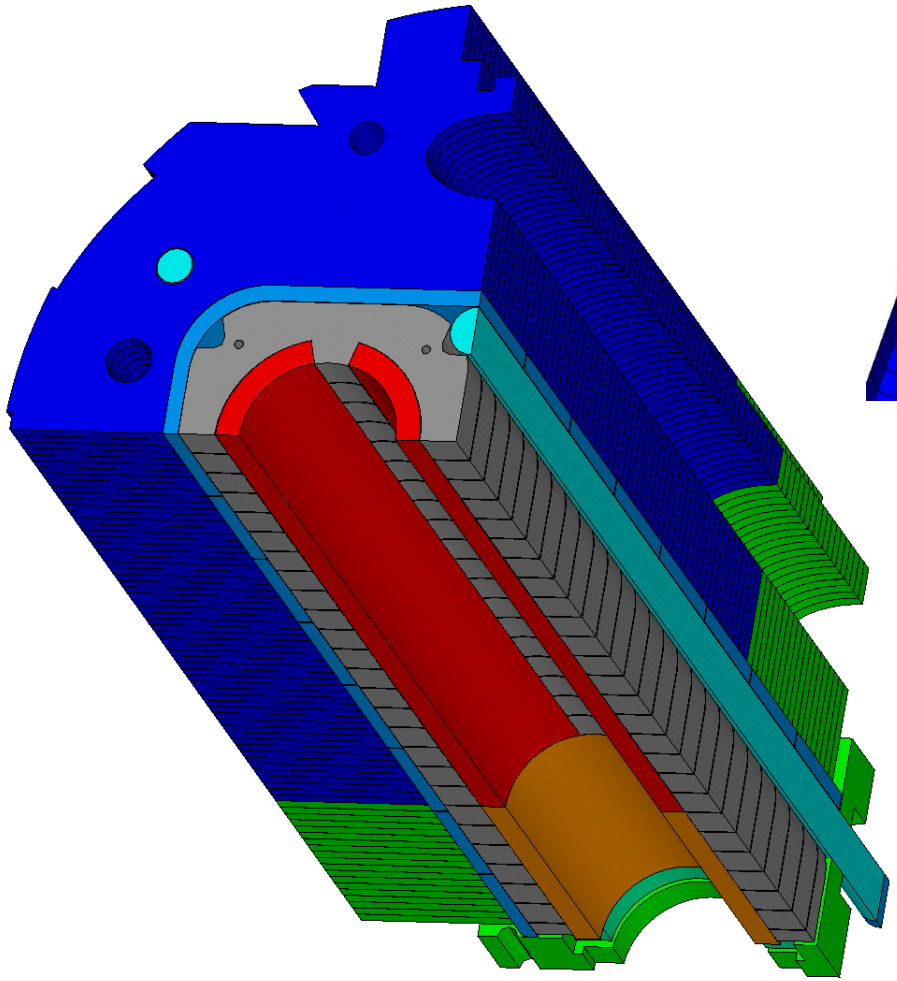


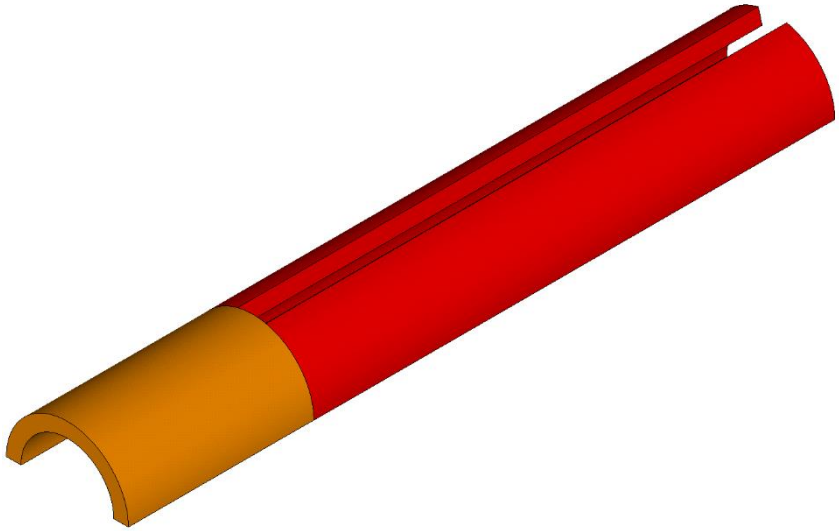


FEA 3D MODEL

FEA 3D model







Longitudinal pre-loading system

- The 6 tie rods (2 M33 and 4 M24) are loaded up to 125 kN, corresponding to 50% of the Lorentz force
- In the last measurement campaign too many strain gauges were lost, so no comparison with FEA is possible
- However, we can compare the results coming from the tests performed last year and already published (*The HL-LHC Short model recombination D2 dipole: Cold test results and analysis*, IEEE Trans. Supercond. 30, 4 , June 2020, DOI: 10.1109/TASC.2020.2976963)

The HL-LHC Short model recombination D2 dipole: Cold test results and analysis, IEEE Trans. Supercond. 30, 4 , June 2020

IV. Cooling Down Phase

The cool down was performed in a vertical cryostat limiting the thermal gradient to 50 K. The initial total axial preload at room temperature of 125 kN +/- 5 in the six tie rods was increased by 15 kN during the cool down.

V. Power Electrical Test

The axial rods were loaded under powering test to a maximum of 20 MPa, i.e 17 % above estimated values, with a linear load increase rate of 118 N/kA^2 on the central largest diameter tie rods compared to 48 N/kA^2 on smaller ones.

Reaction forces on tie rods

FEA results	M33 (kN)	M24 (kN)	Total (kN)
Assembly	30.4	16.1	125.2
Cool-down	29.2	15.8	121.6
Powering	49.8	23.1	192.0

- During cool-down, the initial longitudinal preload was increased by 15 kN
- FEA instead shows a small decrease of 3.6 kN

Reaction forces on tie rods

FEA results	M33 (kN)	M24 (kN)	Total (kN)
Assembly	30.4	16.1	125.2
Cool-down	29.2	15.8	121.6
Powering	49.8	23.1	192.0

- During powering, the M33 rod showed a load increase rate of 118 N/kA^2, corresponding to 18.0 kN at nominal current, the M24 rod showed a load increase rate of 48 N/kA^2, corresponding to 7.3 kN at nominal current.
- At nominal current, FEA shows a load increase between cooldown and powering of 20.6 kN for the M33 rod and 7.3 kN for the M24 rod, in very good agreement with the tests.

Force balance (kN) in magnet components

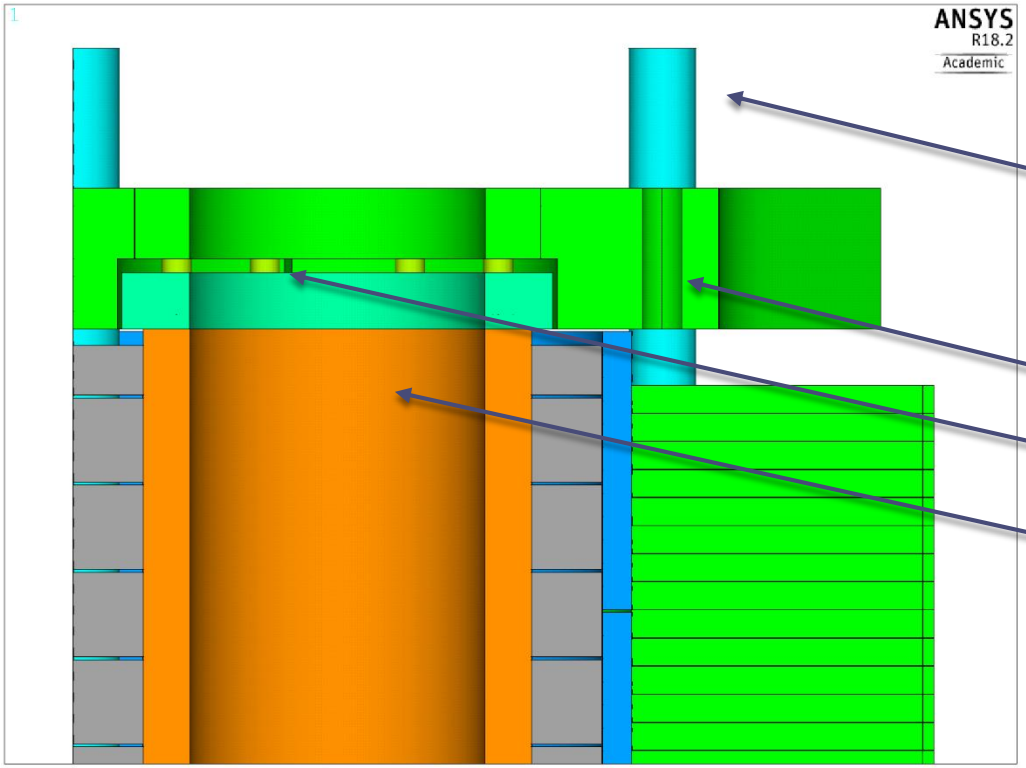
	coil	collars	sleeves	iron yoke	tie rods	total
assembly	-241.3	+116.3	0	0	+125.0	0
cool-down	-102.3	-50.1	+30.7	+0.1	+121.6	0
powering	-12.2	+31.6	+44.5	+0.2	+191.9	+256.0

preload

Lorentz force

- It is worth noting that powering generates a completely different equilibrium between the different reactions with respect to cool-down, so that the tie rods are loaded only by 191.9-121.6=70.3 kN instead of the full 256 kN of the Lorentz force
- In average, we do expect that each bullet, from cool-down to I nominal, is additionally strained by:
  70.3 kN / 16 / 200 GPa / π / (5.3235 mm)^2 = 250 μm/m

Longitudinal preloading system



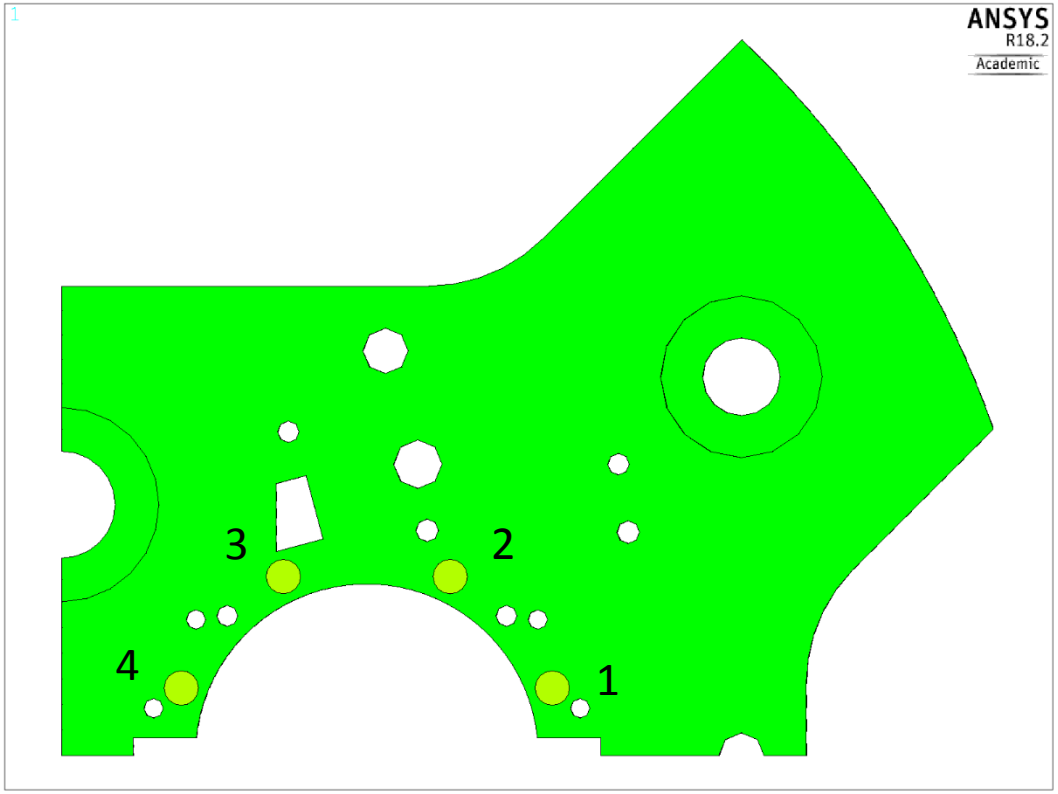
- Preload is applied to tie rods by screwing the superbolts
- Tie rods transfer the load to the flange
- then to the bullet
- and finally to the winding

Bullet gauge measurements

			Test 2020 @ CERN							
			Arrival at CERN	SM18 Insert Room Temp.	I nominal 12.3 kA		Warm Up [12/08/20]	Cool Down [23/08/20]	I nominal 12.3 kA	
	Label	Unit	293K	293K	1.9 K	Loading	293K	1.9 K	1.9 K	Loading
Bullet gauges [kN]	BDL1	µm/m	754	674	825	215	651	572	785	213
	BDL2	µm/m	-620	-510	-703	-188	-483	-478	-660	-181
	BDL3	µm/m	OFVL	OFVL						
	BDL4	µm/m	633	540	836	132	510	693	807	114
	BDR1	µm/m	916	881	827	304	808	483	799	316
	BDR2	µm/m	1053	OFVL						
	BDR3	µm/m	Short-circuit	Short-circuit						
	BDR4	µm/m	OFVL	OFVL						
	BUL1	µm/m	Short-circuit	Short-circuit						
	BUL2	µm/m	-1027	-925	-779	-106	-916	-638	-746	-109
	BUL3	µm/m	-352	-243	-139	-82	-205	-9	-101	-92
	BUL4	µm/m	-966	-846	-827	-214	-798	-567	-794	-227
	BUR1	µm/m	-62	-35	-48	-241	47	224	-11	-236
	BUR2	µm/m	-655	-608	-480	-198	-541	-248	-449	-201
	BUR3	µm/m	-592	-527	-373	-81	-470	-259	-348	-88
	BUR4	µm/m	624	-560	516	184	505	300	493	193

Bullet gauge FEA results

- Measurements: loading between -80 and -240 μm/mm



	1.9 K μm/mm	I nominal μm/mm	Loading μm/mm
1	-510.8	-880.0	-369.3
2	-565.0	-796.5	-231.5
3	-404.5	-568.0	-163.5
4	-285.5	-540.5	-255.0

Average loading strain: 255 μm/m

THANKS FOR THE ATTENTION

Sept. 2nd 2020

S.Farinon (INFN-Sezione di Genova)