Mechanical Design Analysis of MQXFB, the 7.2 m Long Low-β Quadrupole for the High-Luminosity LHC Upgrade

G. Vallone[1], G. Ambrosio[2], N. Bourcey[1], D. W. Cheng[3], P. Ferracin[1], P. Grosclaude[1], M. Guinchard[1], M. Juchno[3], F. Lackner[1], H. Pan[3], J.C. Perez[1], S. Prestemon[3]

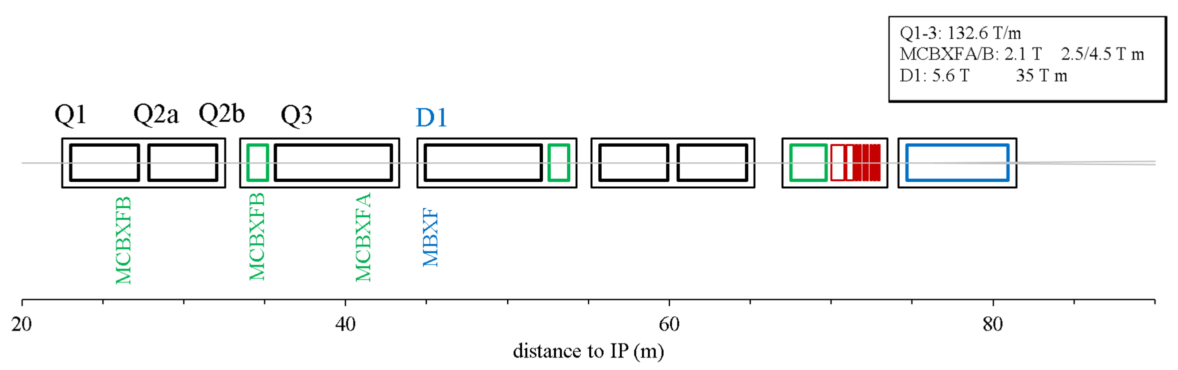
[1]CERN, European Organization for Nuclear Research, Geneva, CH. [2]FNAL, Fermi National Accelerator Laboratory, Batavia, IL,USA. [3]LBNL, Lawrence Berkeley National Laboratory, Berkeley, CA, USA

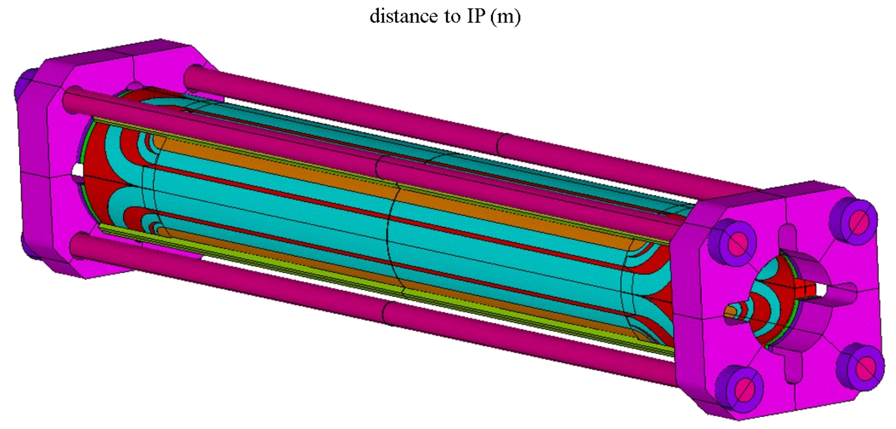
Tue-Af-Po2

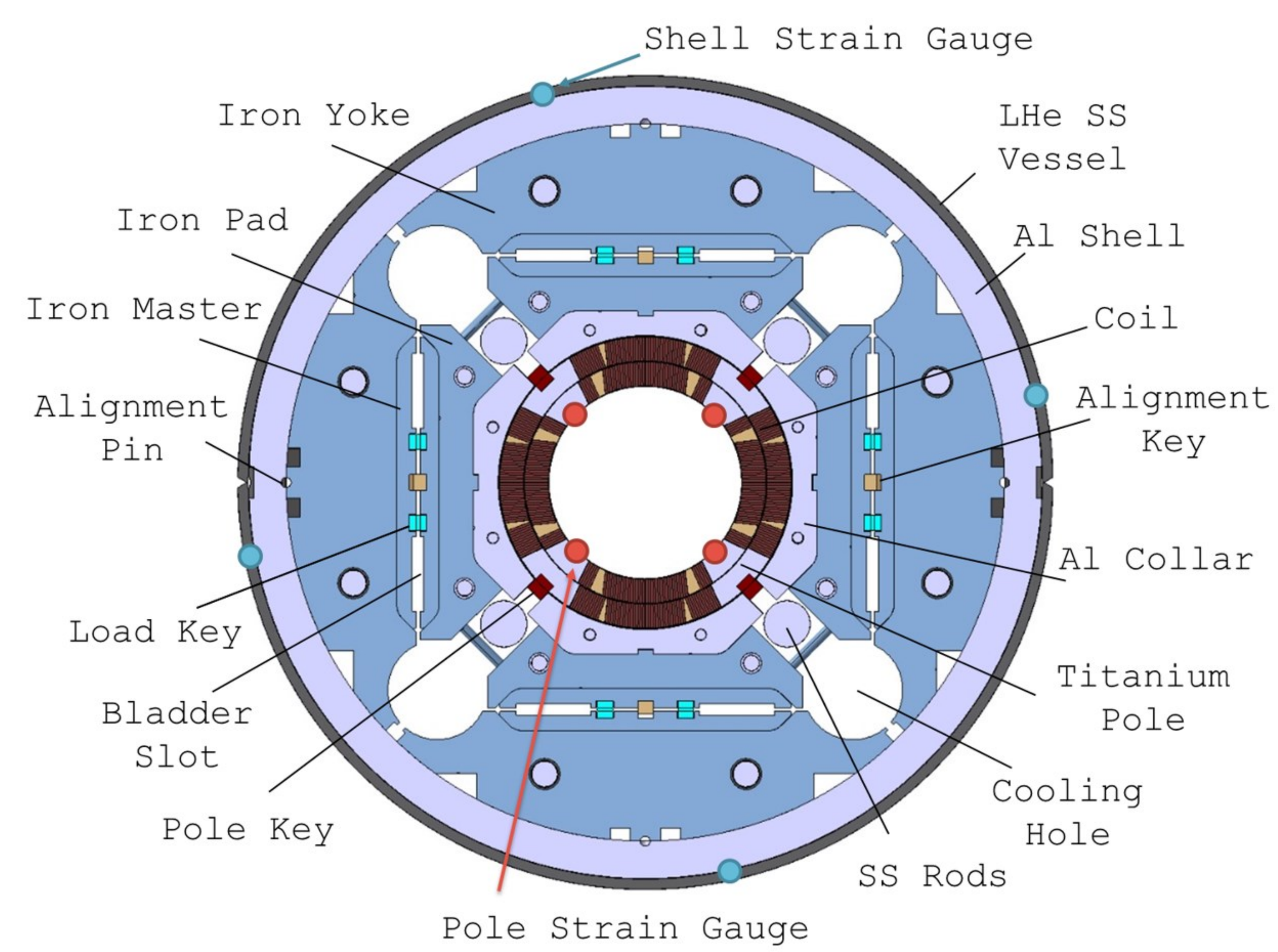
MQXFB Description

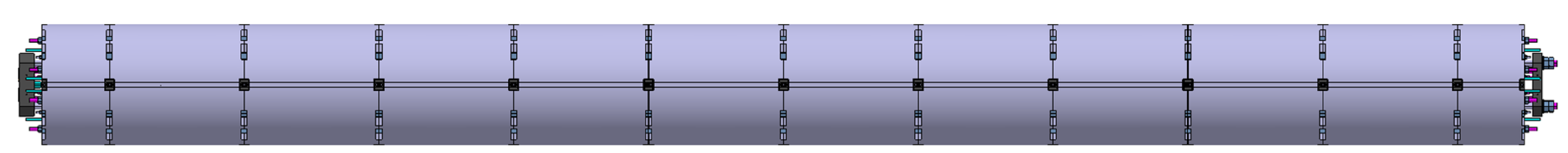
The MQXFB magnets will be installed in the **LHC** as a part of the **High-Luminosity** upgrade. The **Nb_3Sn** magnet will produce a gradient of 132.6 T/m in a 150 mm aperture and a magnetic length of 7.12 m. The conductor peak field will be 11.4 T.

The design was already tested in 3 short models, demonstrating its capability to reach the specified performances. Here, we analyse the **mechanical design** of the MQXFB magnet, highlighting the expected **differences** with the **short models** and discussing the preload conditions required to guarantee a correct mechanical behaviour.







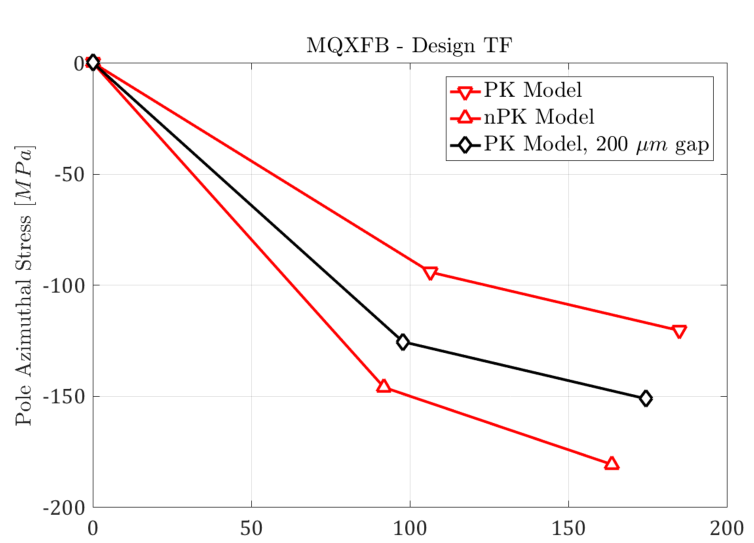


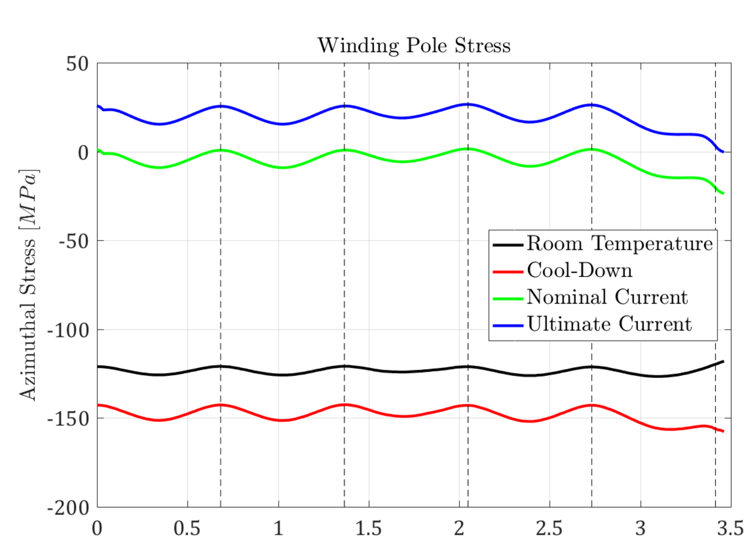
*Experiments show that when an insufficient **prestress** is applied the coil/winding pole/spacers bonding may fail. The consequent motions or even the energy released during the bonding breakage are considered possible **quench origins**.*

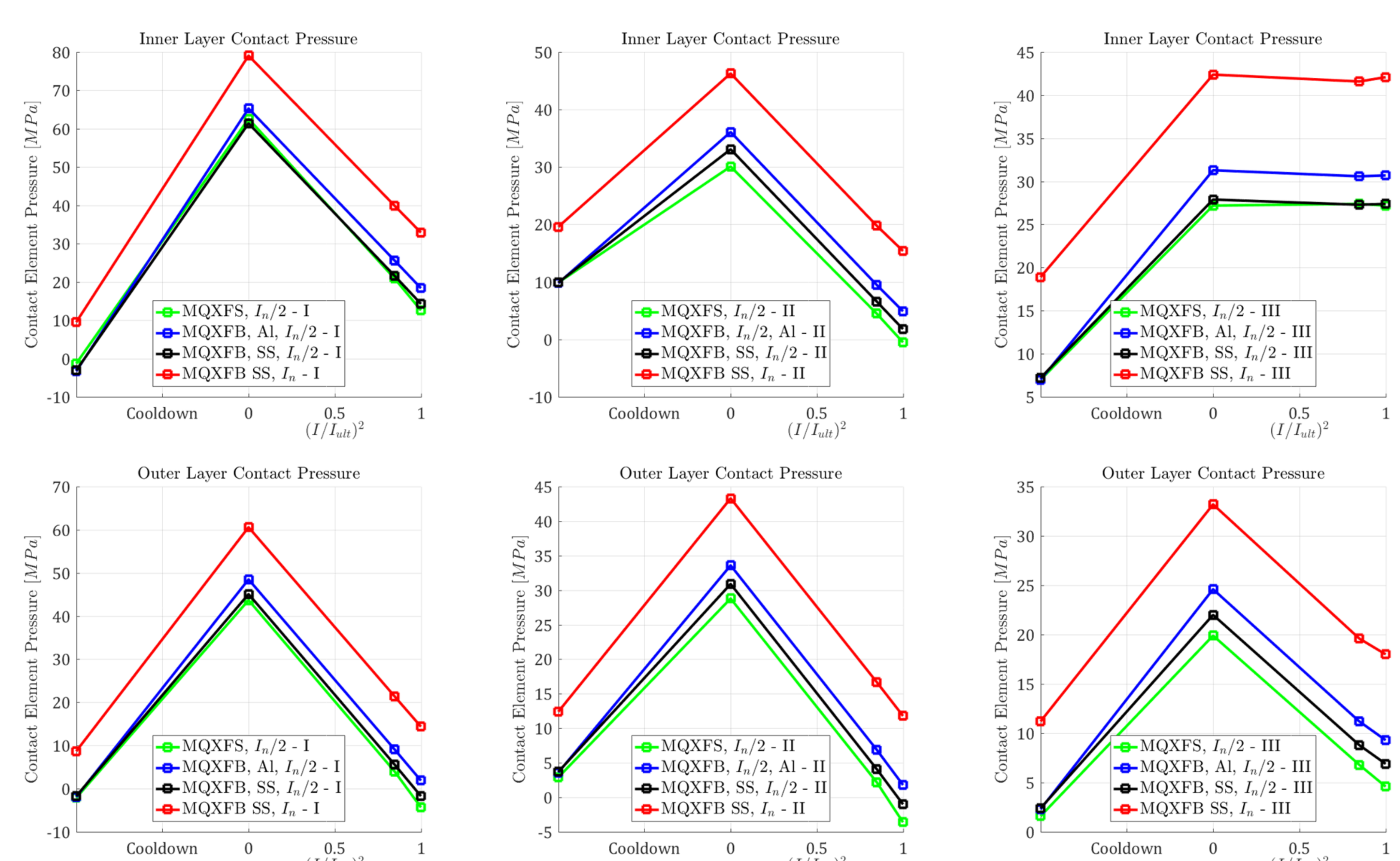
Azimuthal Prestress

MQXF design allows to **control** the azimuthal prestress by varying the loading **key** thickness and the amount of shimming applied on the **pole alignment key**. Computations and measurements from the short models suggested to apply 140-150 MPa on the winding pole to keep the **coil** under **compression** up to ultimate current.

Because of the partitioning of the aluminium shells, the azimuthal **stress fluctuates** with minimum at the shell ends and maximum at the centres. This variation is narrowly contained in a ±10 MPa range. On the short models longer shells were used, reducing this to a ±5 MPa range. However, the **variation** of the stress across the four **quadrants** was ±20 MPa.







Coil Ends Displacements

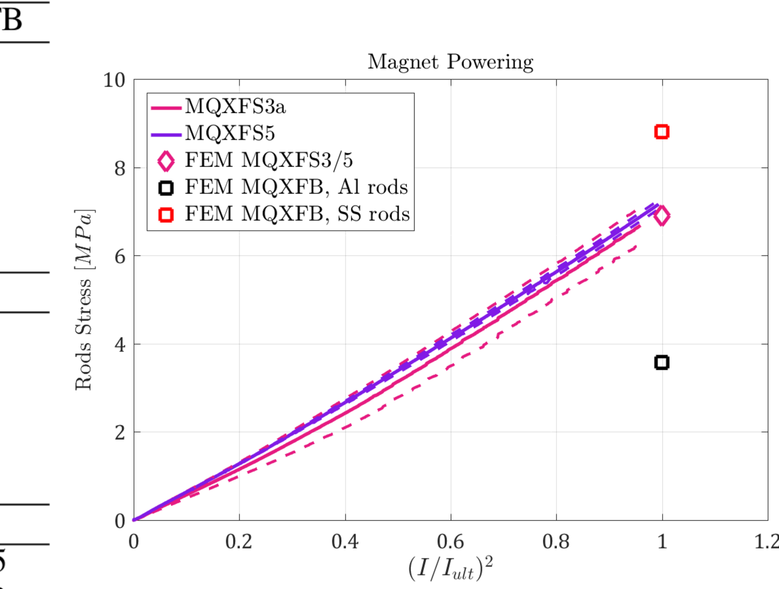
The **longitudinal** e.m. **forces** are reacted by the **coil**, the **longitudinal support system** and the **structure**. These components act similarly to **parallel springs**, and the force repartition is defined by their relative stiffness. Coil stiffness can be computed as:

$$K_{coil} = \sum E_i A_i / L$$

The **structure contribution** was extracted from models, calibrated on the **rods stress measured** on the short models experiments. The model estimates a total motion of the ends equal to 0.28 mm. The estimate for the short model was 0.10 mm.

The structure will react to the 93% of the e.m. forces. The rods will carry only the 3%, the coil carries the 4%. These values do not depend on the azimuthal and longitudinal prestress applied.

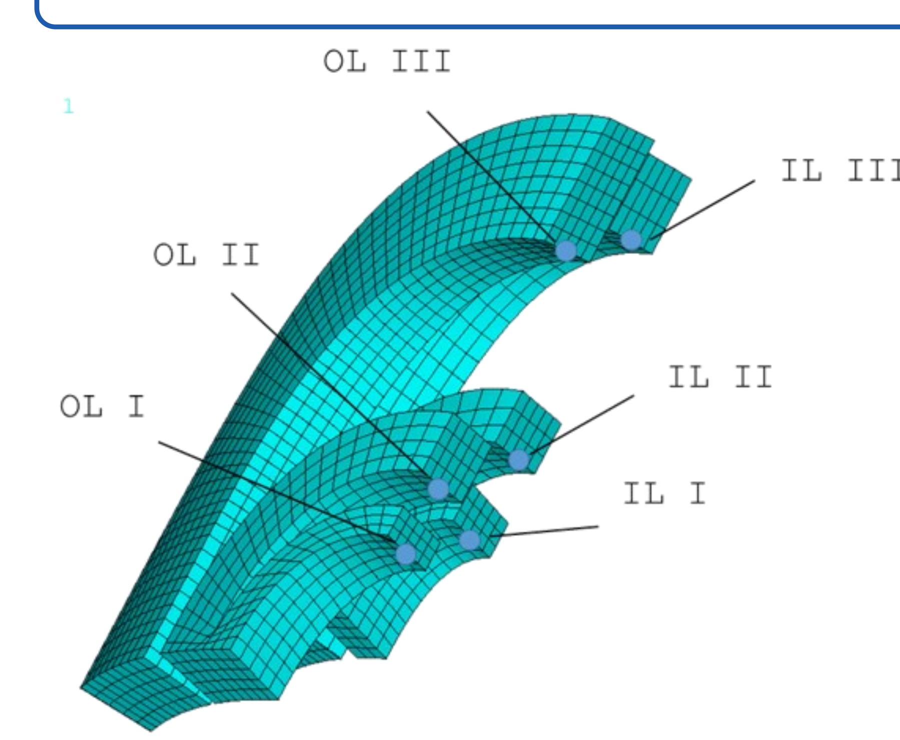
Parameter	Unit	MQXFS	MQXFB
e.m. Force, Nominal Current	MN	1.2	1.2
Coil Stiffness	MN/mm	1.10	0.17
Al. Rod Stiffness	MN/mm	0.21	0.04
SS. Rod Stiffness	MN/mm	0.53	0.14
Coil Length	m	1.08	7.00
Magnet Length	m	1.55	7.51
Coil Elongation:			
No friction, no rods	mm	1.09	7.04
No friction, Al. rods	mm	0.91	5.63
No friction, SS. rods	mm	0.73	4.22
Friction, Al. rods	mm	0.10	0.28
Friction, SS. rods	mm	0.06	0.28
Force Repartition, Coil/Rods/Structure:			
Friction, Al. rods	%	10/2/88	4/1/95
Friction, SS. rods	%	9/5/86	4/3/93



Longitudinal Prestress: Contact Pressures on the Coil Ends

A set of representative locations was selected to verify the **contact conditions** in the **coil ends**. Results show that the MQXFB prestress **increase** during **cool-down** is 40% **larger** than in the short models.

Some locations may undergo **tension** during **powering** when the prestress is not sufficient (IL II, OL I). This suggests that even if the rods are not carrying a meaningful part of the e.m. forces, the **longitudinal prestress** is of foremost importance to guarantee a **proper contact** condition in the coil end-region during powering.



Rods Longitudinal Stress - MPa			
	R.T.	CD	I_{ult}
MQXFS3a, $I_n/2^\dagger$	56	168	173
MQXFB, Al. Rods, $I_n/2$	62	219	223
MQXFB, SS Rods, $I_n/2$	64	187	196
MQXFB, SS Rods, $I_n^\ddagger$	174	302	311

† Rods force at cold equal to half of the e.m. force at nominal current I_n.
‡ Rods force at cold equal to the e.m. force at nominal current.

Presented at the 25th International Conference on Magnet Technology RAI, Amsterdam. August 27– September 1, 2017