Design of the resistive insert of the Nijmegen 45 T hybrid magnet

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Frans J.P. Wijnen, Chris A. Wulffers, Arno Engels, Andries den Ouden, Jos M.H. van Velsen, Jos A.A.J. Perenboom
High Field Magnet Laboratory (HFML-EMFL), Radboud University, Nijmegen, the Netherlands

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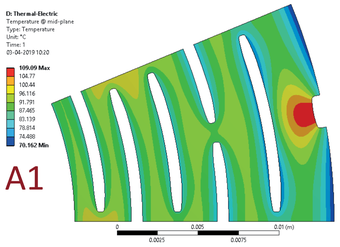
Introduction

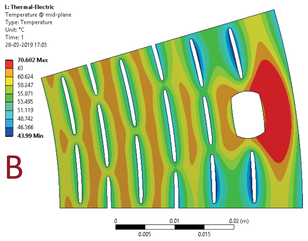
The High Field Magnet Laboratory (HFML) in Nijmegen is constructing a 45 T hybrid magnet. We present the design of the 33 T resistive insert magnet that will operate in a 620 mm room temperature bore, 12.3 T superconducting outsert magnet.

Main design restrictions:
32 mm room temperature bore
618 mm outer diameter, including housing
Max. 40 kA, 525 V (21 MW)
Maximum fault force to outsert 2.5 MN
Cooling water flow ~150 l/s at 24 bar pressure drop

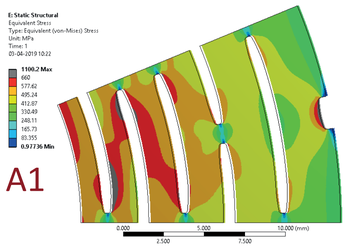
Coil & Disk Design

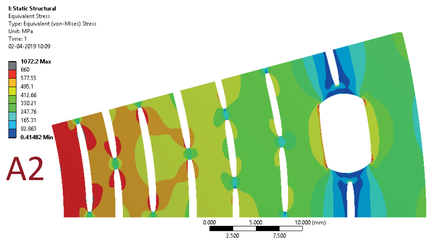
Property	Unit	A1	A2	B	C	D
Inner radius	mm	19	36	78	122	181
Outer radius	mm	35	75	119	178	276
Height	mm	394	395	598	695	700
Coil weight	kg	9.6	48.0	136	329	855
Self-field	T	6.46	8.63	6.53	5.22	6.39
Total field	T	33.24	26.78	18.14	11.61	6.39
Power	MW	1.86	3.79	4.58	3.95	6.45
Voltage	V	141.4	141.4	114.6	98.7	161.2
Current density	A/mm²	603.2	344.8	213.6	111.2	95.4
Power density	W/mm³	9.92	3.11	1.17	0.23	0.17
Temperature rise in case of cooling loss	K/s	2868	900	338	67	50
Hoop stress (jrB)	MPa	600	533	562	346	354
FEA stress	MPa	660	660	650	333	300
FEA temperature	°C	120	86.8	81	60.5	68.7
Coil Temperature	°C	77.7	62.3	54.6	38.5	45.5
Cooling flow	l/s	11.2	23.8	30.9	35.2	59.2
Water velocity	m/s	17.7	17.4	14.4	14.7	15.7

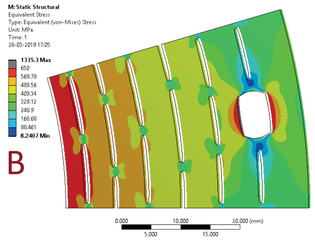


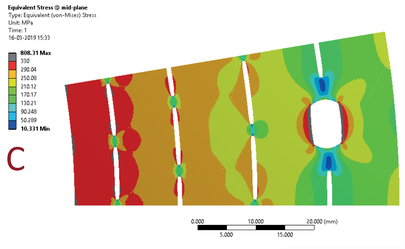


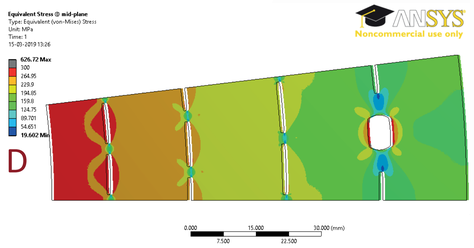
FEA Results









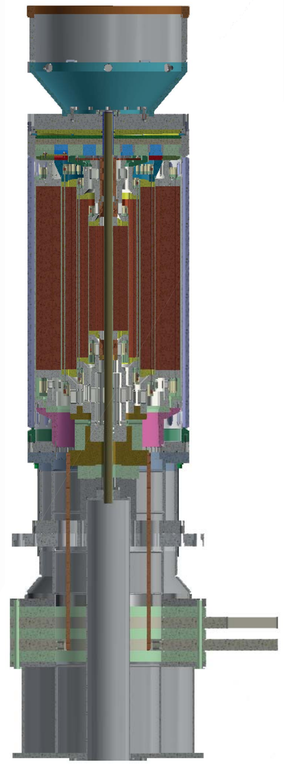


Housing

Top section holds the coils that can be exchanged one-by-one or as the entire coil set.
Bottom section of the housing has the connections for the cooling water (150 l/s, 24 bar) and the electrical power (22MW).
Both sections are inserted into the outsert from below and connected in-situ.

Left-hand side picture shows the outside of the housing, includeing the wedges at the lower end of the coil, used to adjust the radial alignment of the insert magnet.

Right-hand side picture shows a cross-section of the housing, revealing the coils, the support structures for the coils and other internal components.



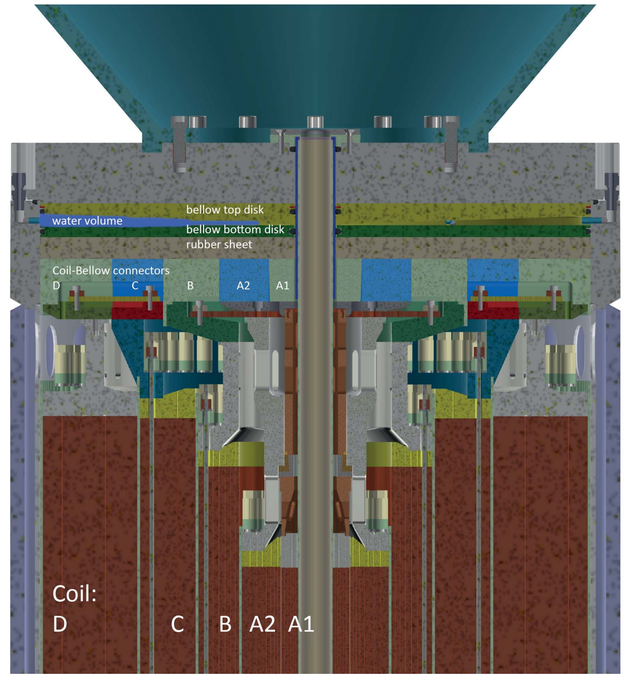
Water-pressurised Bellow

Clamping of the coil is always an issue: ends of the coil are not clamped and therefore end turns are loose, which leads to displacement and (partial) blocking of cooling holes.

We install a water-pressurised bellow that always exerts sufficient clamping stress on the coil, holding the end turns in place. The stress in the end turns can then be described by a hoop stress problem and conventional current density grading provides a handle to reduce the hoop stress to acceptable levels.

The bellow acts like a lever in case of a fault force in one of the coils.
Surface area of coil and connecting block are carefully tuned to restrict the maximum pressure in the bellow to 215 bar under the worst-case fault force scenario.

Property	Unit	A1	A2	B	C	D
Force at end turn	kN	11.4	43.2	83.8	102	111
Compressive stress to hold end turn by friction, m=0.2	MPa	10.5	7.9	8.3	4.8	2.0
Bellow/Coil surface ratio		2.20	1.55	1.64	1.05	0.81
Bellow operating pressure	bar			100		
Compressive stress on coil	MPa	22.0	16.8	17.5	11.2	8.1
Safety factor		2.1	2.1	2.1	2.3	4.0
Fault force (possible)	kN	98.5	600	1231	1694	2988
Bellow pressure	bar	83	131	138	143	135
Force on top cover	kN	2009	3189	3368	3477	3292
Fault force (worst-case)	kN	as above			2551	4754
Bellow pressure	bar				215	215
	kN				5238	5237



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