EuroCirCol 16 T block-coils dipole option for the Future Circular Collider

ID: 2LPo1D-03 [30]

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European Commission | Horizon 2020 European Union funding for Research & Innovation

sx: horizontal stress

svm: von Mises stress

sl: maximal principal stress

Introduction: EuroCirCol is a conceptual design study for a post-LHC research infrastructure based on an energy-frontier 100 TeV circular hadron collider [**1LOr3C-02**]. In the frame of the high field accelerator magnet design work package of this study, three different layouts for double-aperture dipole magnets made of Nb3Sn conductors and providing a field of 16 T in a 50-mm aperture are being considered: block-coils, common-coils [**2LPo1D-08[35]**] and cosine theta [**2LPo1D-02[29]**]. This poster details the block-option presently under development at CEA.

1) Electromagnetic analysis: double aperture configuration
2) Mechanical analysis: single aperture configuration

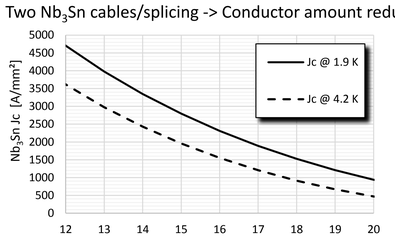
Main baseline parameters:

Parameter	Values		Unit
Operating temperature	1.9	-	K
Aperture diameter	50	-	mm
Nominal field amplitude	16	-	T
Beam-beam distance	250	-	mm
Yoke outer diameter	800	-	mm
Margin on the load-line @ 1.9 K	>18	>14	%
Critical current density @ 1.9 K, 16 T	2310	-	A/mm²
Copper/non-Copper ratio (cnc)	>1.0	>0.8	adim
Number of strands per cable	<40	<60	adim
Hot spot temperature (@ 105% I_{nom})	<350	-	K
Strand diameter	<1.1	<1.2	mm
Stress on conductor at warm	<150	-	MPa
Stress on conductor at cold (@ 105% I_{nom})	<200	-	MPa
Voltage to ground (magnet only)	<1.2	-	kV
Harmonic b3 (@ I_{nom})	<3	-	10^{-4}
Harmonic b5 (@ I_{nom})	<5	-	10^{-4}
Harmonic b7 (@ I_{nom})	<3	-	10^{-4}
Harmonic b2 (@ I_{nom})	<20	-	10^{-4}
Harmonic b3 (@ 1 T injection)	<10	-	10^{-4}

Baseline before and after the external review May 2016.

Nb_3Sn critical current & cable dimensions:

Two Nb_3Sn cables/splicing -> Conductor amount reduction by a factor 2 for cost savings [**2LPo1D-07[34]**]

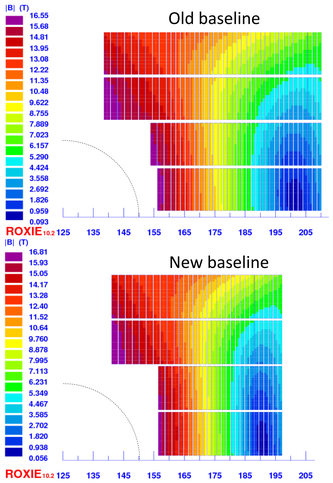


$$\begin{cases} J_c = \dfrac{C(t)}{B} b^{0.5}(1-b)^2 \\ B_{c2}(T) = B_{c20}(1-t^{1.52}) \\ C(t) = C_0(1-t^{1.52})^{\alpha}(1-t^2)^{\alpha} \end{cases}$$

where $t = T/T_{c0}$ and $b = B/B_{c2}(t)$ with B the magnetic flux density on the conductors. T_{c0} = 16 K, B_{c20} = 29.38 T, α = 0.96, C_0 = 275880 AT/mm² are fitting parameters computed from the analysis of measurements on the conductor. The cabling degradation is assumed to be 3%.

Parameter	Values		Unit
Strand diameter	1.1	0.7	mm
Number of strands	24	39	adim
Width	14.25	14.25	mm
Copper/non-Copper ratio (cnc)	0.8	1.6	adim
Insulation thickness	0.15	0.15	mm

Electromagnetic analysis - Roxie:



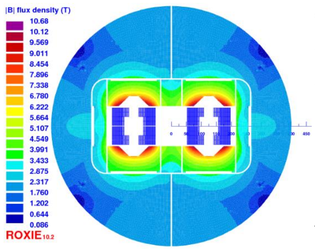
Parameter	Values	Unit
Nominal current	10930	A
Peak field	16.81	T
Loadline margin	13.95	%
Inductance (2 apertures)	48.06	mH/m
Stored energy (2 apertures)	3016	kJ/m
Horizontal force (per ½ coil)	8473	kN/m
Vertical force (per ½ coil)	3572	kN/m
Bore thickness	6.3	mm
Mid-plane shim	1.45	mm
Hotspot	348*	K
Voltage to ground	1065*	V
Number of turns HF cable per layer	3+3+9+9 = 24	adim
Number of turns LF cable per layer	22+22+23+23 = 90	adim
Area of conductor (2 apertures)	151.9	cm²
Total weight**	8652	tons

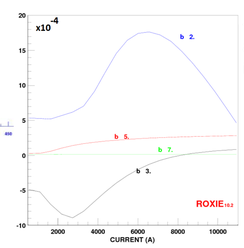
New baseline

*see [**2LPo1A-10[9]**] for details

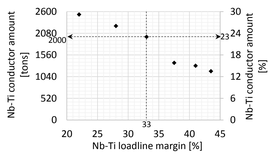
**given as an indication for 4578 dipoles, 14.3 m long each, and a conductor density of 8700 kg/m³.

Old basline: 10821 tons





<- Field quality of the double aperture configuration from injection at 1 T to operation at 16 T.



Mechanical analysis - Ansys:

Bladder&Key structure U.S. LARP

Material	E [GPa]		pr	$(L_{4.3K}-L_{293K})/L_{293K}$
	293 K	4.3 K	293K /4.3K	293 K -> 4.3K
Nb_3Sn	EX = 44 EY = 52 GXY = 21	EX = 44 EY = 52 GXY = 21	0.3	X = 3.36e-3 Y = 3.08e-3
StSt	193	210	0.28	2.84e-3
Iron	213	224	0.28	1.97e-3
Al7075	70	79	0.34	4.2e-3
Ti6Al4V	130	130	0.3	1.74e-3

Material	$R_{p0.2}$ [MPa]	
	293 K	4.3 K
Al 7075	480	690
SS 316 LN	286	930
NITRONIC 40	353	1240
MAGNETIL*	180	723
Ti 6Al 4V	827	1654

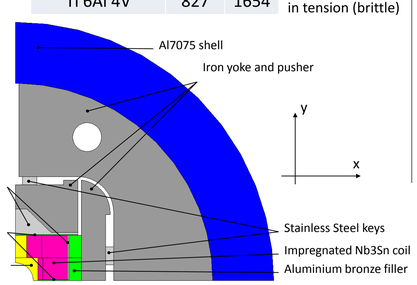
*Iron @ 4.2 K stress < 200 MPa in tension (brittle)

stress in [MPa]]	y-stress	x-stress	von Mises
Key insertion	54	113	103
Cool-down	64	211	204
Powering @105% of Inom	118	195	180

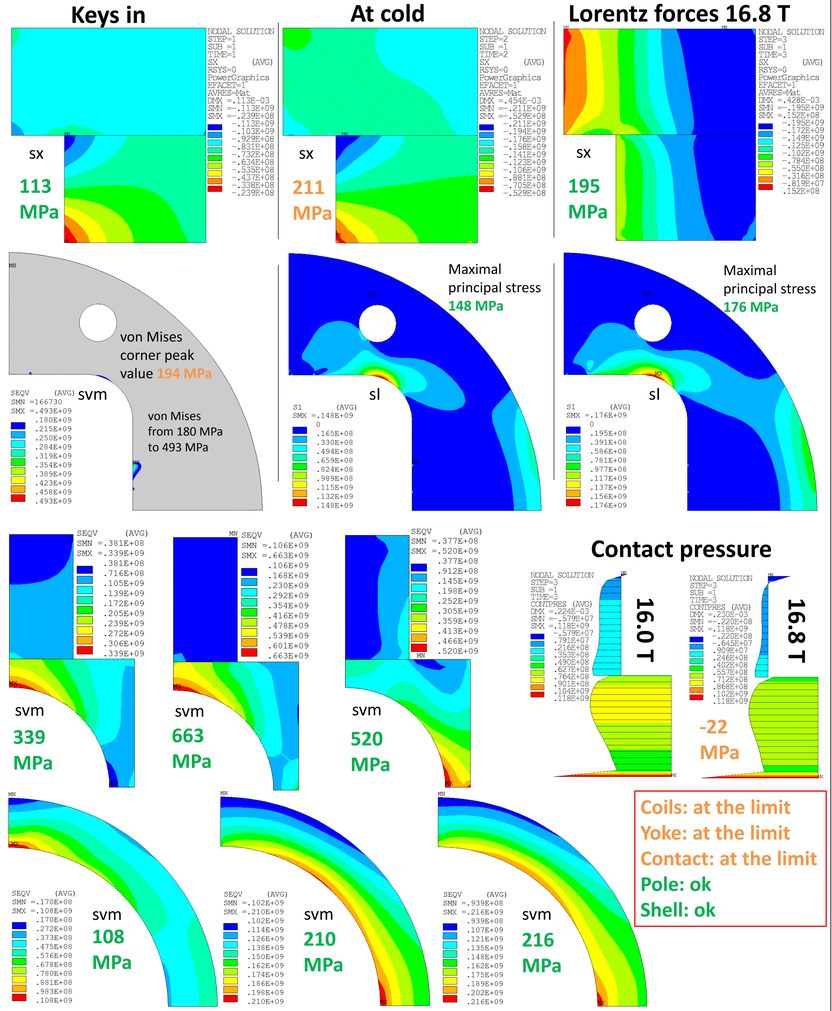
Stainless steel pads

G10 shims

Ti6Al4V pole



EuroCirCol is co-funded by the partners and the European Commission under H2020 Framework Programme, Grant Agreement 654305



Conclusion: An investigation about to use block coil configuration for 16 T accelerator dipole has been started showing that internal grading of the coils is mandatory to reduce the amount of conductor. So far, the total amount of Nb_3Sn conductor would be ~8650 tons for the FCC machine. With a two step grading ~2000 tons could potentially be replaced by Nb-Ti. The actual magnet configuration meets all the electromagnetic requirements. Nevertheless, a deeper analysis is needed to address all challenging mechanical requirements and must be pursued in 3D to properly analyze end effects and axial loading.