FCC Week 2019

Design Status of a Fast Cycled Low Loss 6T Model Dipole Cooling at 1.9 K

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Outline

- FCC motivated design issues
- The model dipole concept
- Wire, Cable, Coil
- Power losses
- Summary
- Near Future Plan

FCC motivated design goals

- Increasing the SPS energy up to 1.3 TeV within the same tunnel that require SC magnet system.
- Dipole magnets should operate at 6 T in cycled mode to provide proton beam injection into the FCC chain and feed existing areas at 0.45 TeV.
- **SC SPS requires new design of all magnet parts aimed at minimization of power losses (wire, cable, yoke etc.)**

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approved in Dec. 2017 up to March 31, 2019.

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- focus on bending magnets at the first stage;

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- new dipole should have large dynamic range of operation from injection to top energy and minimal level of the cycling power losses **i.e. a cycled SC machine could be quite advantageous in terms of electrical consumption with respect to the normal conducting SPS).**

Model dipole design issues

- The aperture diameter **80 mm**
- Top/injection field: **6.0 / 0.12 T**
- Field quality: **adequate to the modes**
- Ramp rate: **0.2 T/s and 0.5 T/s**
- Coil temperature: **1.9 K**
- Iron yoke: **laminated, low losses**

Total thermal losses should be limited to:

tentatively **< 2 W/m at 4.2 K** equivalent at ramping.

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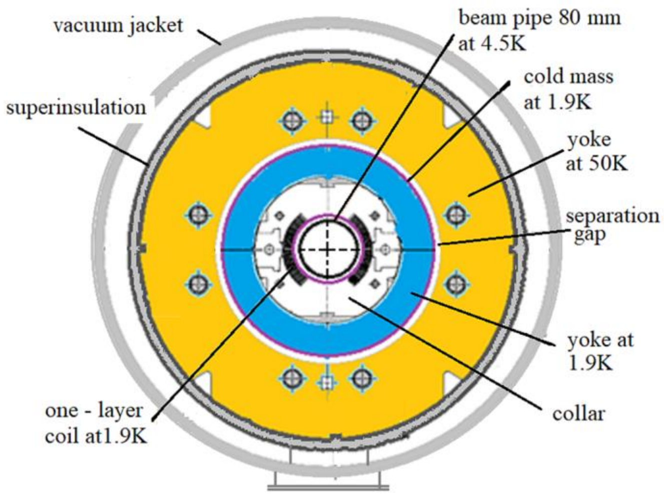
One-layer coil 6 T Pulsed Dipole (1)

Expected profit:

- Minimum power losses in the coil at 1.9 K
- Better heat transfer from the winding



Basic features:

- reduced NbTi amount (higher Ic @1.9 K)
- adequate filament size and twist pitch;
- optimal number of coil turns (Im ~13 kA);
- separated yoke: min. at 1.9 / rest – 50 K;
- some other possibilities...

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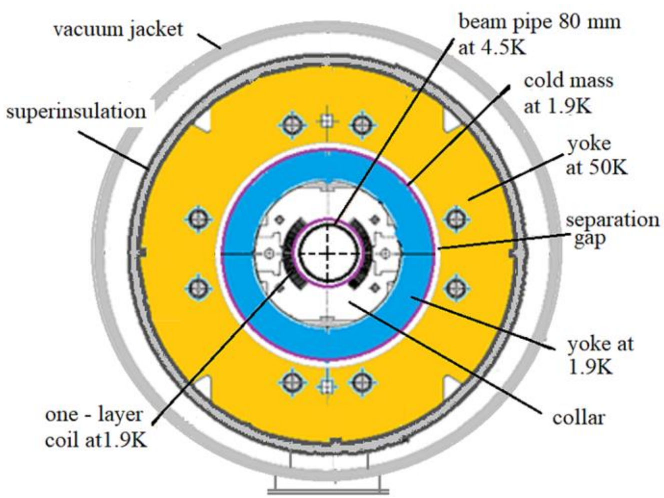
One-layer coil 6 T Pulsed Dipole (2)

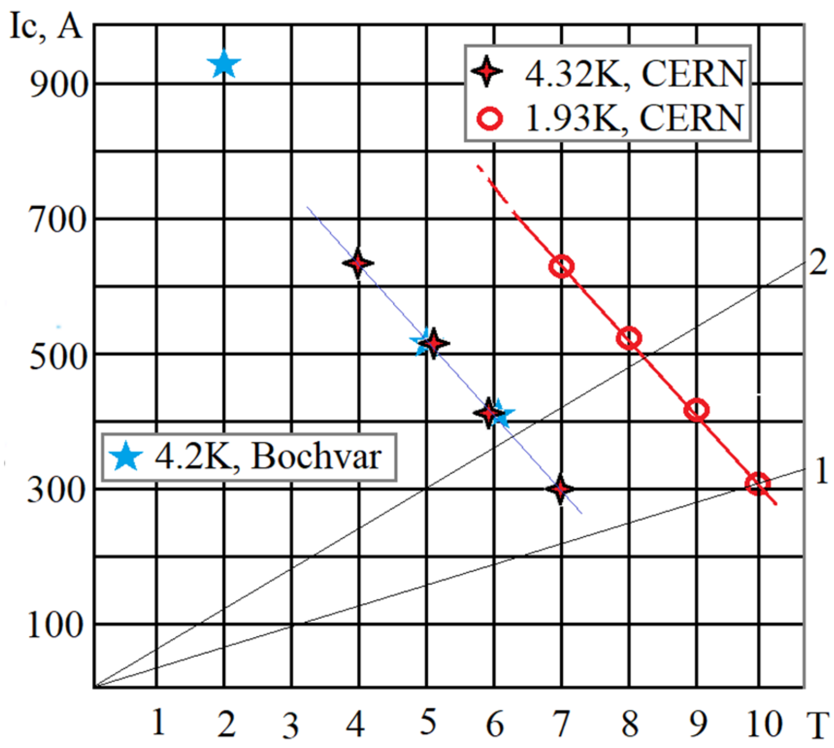
- One-layer coil RHIC dipole: B = 3.4 T, 80 mm aperture at 4.2 K, I = 5 kA.
- Increase of I by a factor of 2 at 1.9 K can give the 6 T in the dipole.
- Dipole option with separated cold mass 4.5/80K was tested experimentally using 2T Nuclotron-type model.



The cold mass at 1.9 K includes the coil, stainless steel collar and some part of laminated yoke (optionally). Current transport lines is placed inside a welded stainless steel vessel, the vessel is centering inside 50K part through low heat transfer support parts. The 50K cold mass is assembled inside special support frame taking also the necessity of minimization eddy current loss into account.

Wire, Cable, Coil (1)

- **The conductor for the first model cable samples and coil fabrication is ready. It was manufactured by the Bochvar research Institute (Moscow). The wire samples were tested for critical current by the manufacturer and at the CERN test facility. The measured data are in a very good agreement.**



The wire parameters are the following:

- **wire diameter – 0.81 mm,**
- **filament diameter – 3.2 mkm,**
- **filament twist pitch – 8 mm**
- **Cu/nonCu ratio – 1.38**

The load lines 1 and 2, taking 30% margine to the maximum field at the coil, are shown at the plot also.

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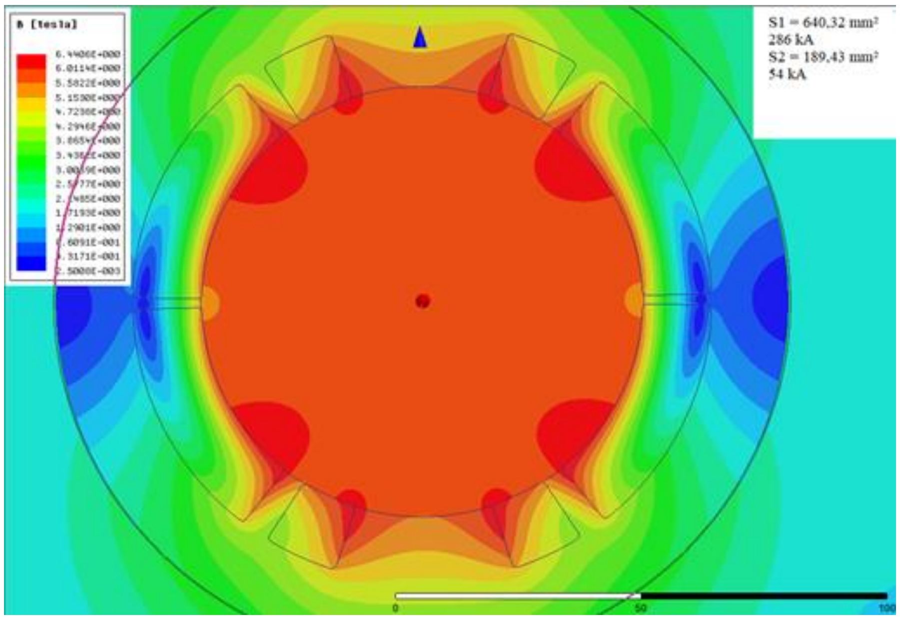
Wire, Cable, Coil (2)

- The coil optimization was performed aimed at minimizing the difference between central and coil fields. The result has been obtained is: Bcoil/Bcent = 6.4/6.0. (not final) . Thus, the Ic = 500 A per wire can be taken.

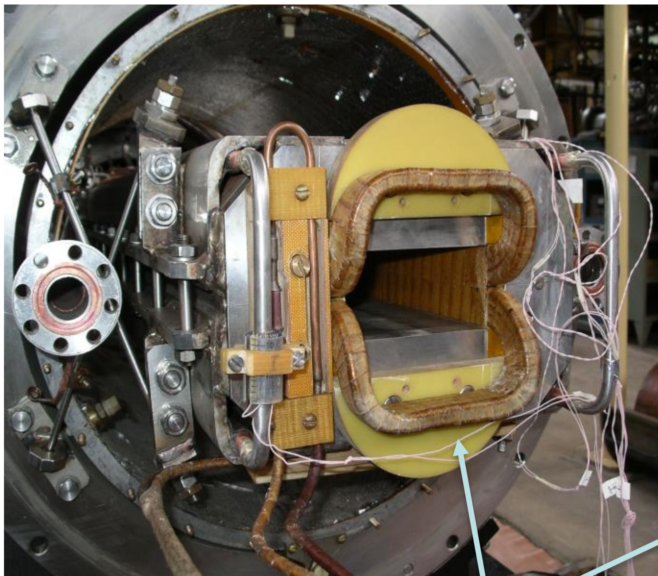


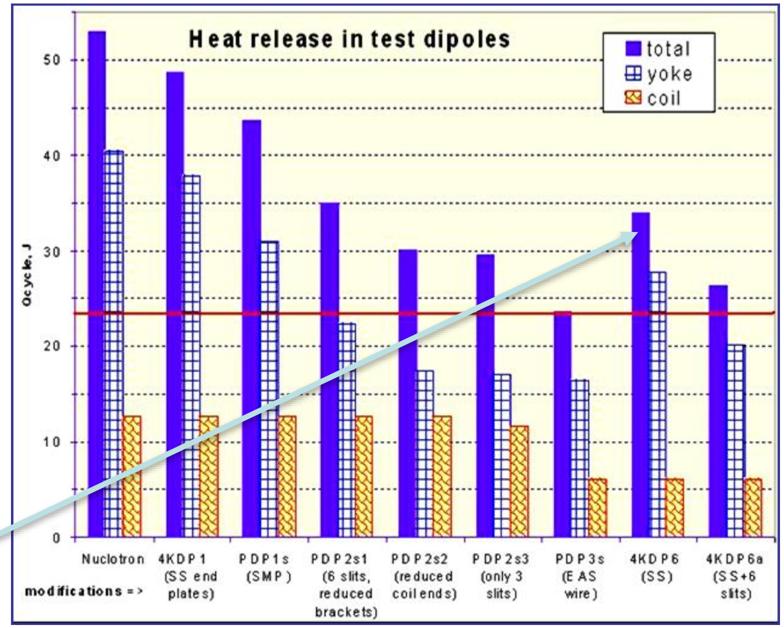
Taking the cable thickness, available azimuthal space and possible number of the turns into account, one can obtaine that it is necessary to provide operating current: Io = 11.16 kA, and the number of wires in cable should be 2 x 11.16 = 22.32 (24 enough!). The cable cross section is 1.61 x 10.8 mm2 (without insulation).

- The cable mechanics should take cycling load into account. Redistribution of the forces to the wires inside cable surface is very desirable.

Estimation of Power Losses (1)

We use experimental data on the losses obtained from the Nuclotron-type SIS100 model dipoles design. The R&D stages are presented at the plot.





Model 4KDP6 AC losses at 2 T, 4 T/s, 1 Hz = 33.9 J per dipole (1.4 m long)

- **Qmag = 17.1 + 4.2 dB/dt (J/cycle) – fit obtained from the measured data;**
- **Qcoil = 2.51 + 0.71 dB/dt (J/cycle) - scaled from cable short sample data (filament 4.2 mkm, Vsc = 157 cm^3);**
- **Qyoke = 14.5 + 3.49 dB/dt (J / cycle) - calculated as (Qmag – Qcoil).**

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Estimation of Power Losses (2)

SIS100 model: Coil loss – 3.5 W/m, 4 T/s, 2 T, 1 Hz, apert. 55x120 mm2. 4.2 μm filament, 0.5 mm wire, 31 wire, twist pitch of ~12 mm.

SPS/Nucl. cycle: – k1 = 3, k2 = 0.05 – 0. 125, k3 = 1/24; 1/60 Hz.
k1,k2,k3 –scale coefficients for the field, field ramp, pulse repetition rate respetively.

Parameter	unit	4T/s, 4.5K	0.2T/s, 1.9K	0.5T/s, 1.9K
Peak field	T	2	6	6
Pulse repetition rate	Hz	1.0	0.016	0.04
Filament diameter	μk	4.2	3.0	3.0
Twist pitch	mm	12	7	7
Coil aperture	mm	120x56	Ø90	Ø90
Iron thickness	mm	0.5	0.5	0.5
Power losses:	W/m			
Coil hysteresis		2.51	0.09	0.23
Coil eddy current		2.84	0.04	0.07
Yoke:magnetization		14.6	0.5	1.31
eddy current		14.0	0.56	3.5
Total	W/m	33.96	1.19	5.10

Yoke loss: 3.5 W/m, at 0.5 T/s out of the limit (< 2 W/m).

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Summary

- Different options of SC magnets were considered, one-layer coil with the difference between central-to-coil field of 7% was chosen;

- Optimized option of a half coil consist of 29 turns supplied by 11.16 kA @ 6 T in the magnet aperture of 80 mm;

- The cable should consists of 24 wires (minimal). The cable critical current reach Ic =16.8 kA in this case;

- The coil AC losses estimated based on experimental data from the SIS100 model dipole design are 0.3 W/m at 0.5 T/s and 0,13 W/m at 0.2 T/s.

- Despite of low ramp AC losses in the iron yoke and constructive element can contribute substantially to the total loss, thus it's better to remove it as much as possible to 50 K temperature level.

Future Work Package

- Manufacturing and tests of cable samples;

- Design and preparation of a test coils and model cold mass;

- Technical design of a model dipole;

- Tests of the model cold mass;

- Manufacturing of the first model dipole;

- Work tests of the model, analysis of the results;

Thank you for your attention