6 T Dipole for the SPS Upgrade

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Outline

- Introductory remarks
- FCC motivated design issues
- Start estimates of the new 6T dipole
- Summary & Outlook

Research goal

- Increase the SPS energy to 1.3 TeV replacing normal conducting magnet system by a superconducting one.
- The SPS would operate in cycled mode to feed experimental areas, like nowadays.
- Innovative design and new development approaches will be required to cope with the AC losses in the superconducting cables.

The R&D can benefit from the CERN, JINR and the other world experience accumulated

Scope of the collaboration (1)

- focus on bending magnets at the first stage;
- **new dipoles offer the peculiarities:**

- the large dynamic range from injection to top energy;

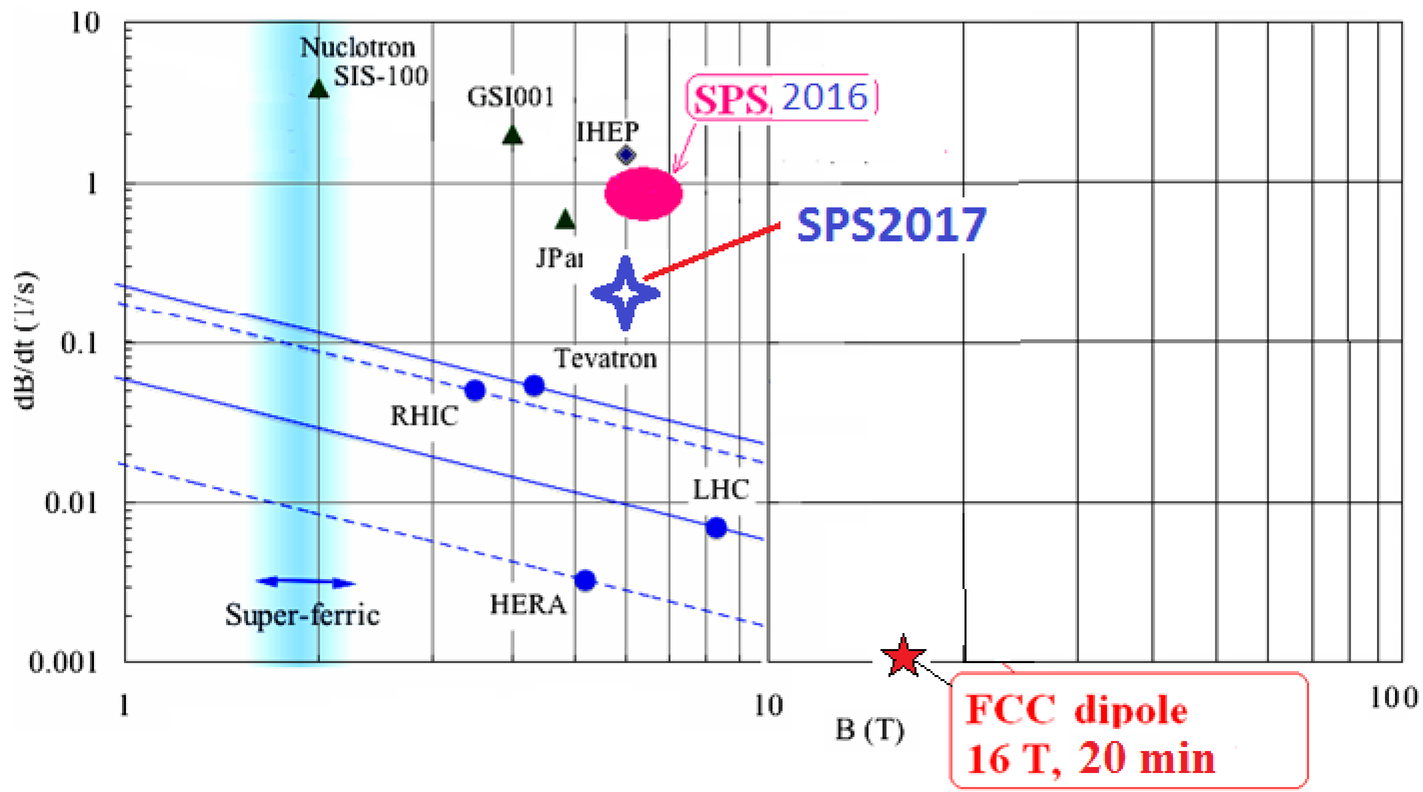
- the minimization of the cycling losses.

(this point is particular essential, as a cycled SC machine could be quite advantageous in terms of electrical consumption with respect to the SPS).

Magnet design issues

- State of the art of Nb-Ti wire for fast cycled magnets, addressing filament size, resistive barriers, amount of stabilizer, type of matrix, RRR and critical current density;
- The magnet aperture: circular 80 mm diameter;
- Top/injection field: **6 / 0.12 T** (1300/25 GeV);
- Field quality: *adequate to different modes of operation;*
- Ramp rate: analyse **0.2 T/s and 0.5 T/s;**
- Coil operating temperature: **1.9 K** (*superfluid helium);*
- Iron yoke: low losses laminated yoke (possibly warm);
- Total thermal losses: tentatively < 2 W/m at 4.2 K equivalent while ramping.

Magnet design options

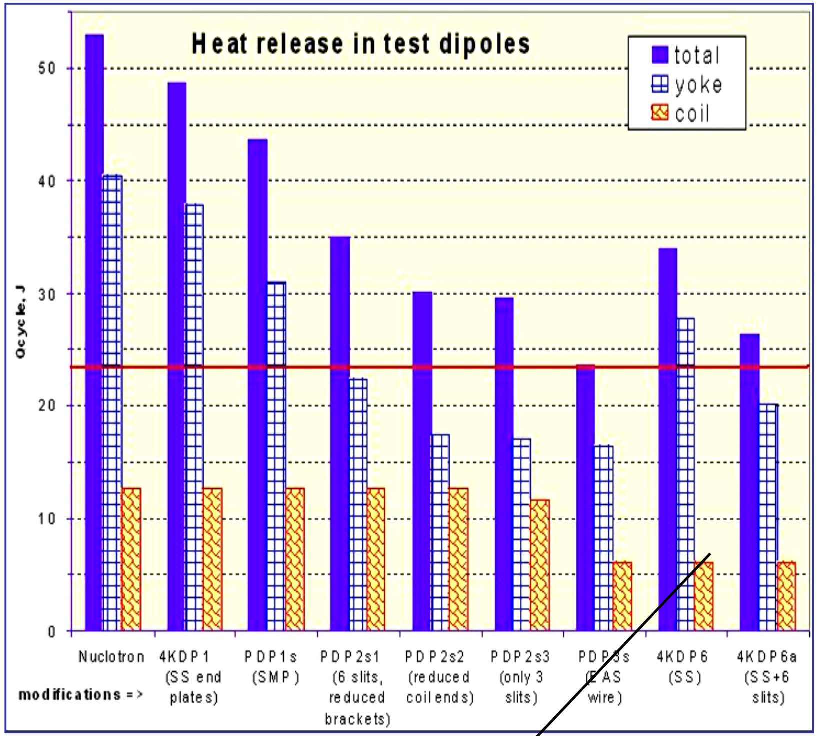


The set of design issues for the new SPS magnet is innovative

Alexander D. Kovalenko,, Attilio Milanese, FCC Week2017, Berlin , 01 June, 2017

Improvement of Nuclotron magnets

JINR/GSI: SIS100 (Y2000/2010): 2T, 4T/s,1Hz, magnet aperture 120x56 mm, length – 1.4 m.



RESULTS:

- ***AC loss was reduced by a factor of 2;***
- ***stabile operation for 10E8 cycles was guaranted***

The coil AC losses ~20% compare to the yoke

LHC: CERN/KEK collaboration

Test Results of a Single Aperture Dipole Model Magnet for LHC

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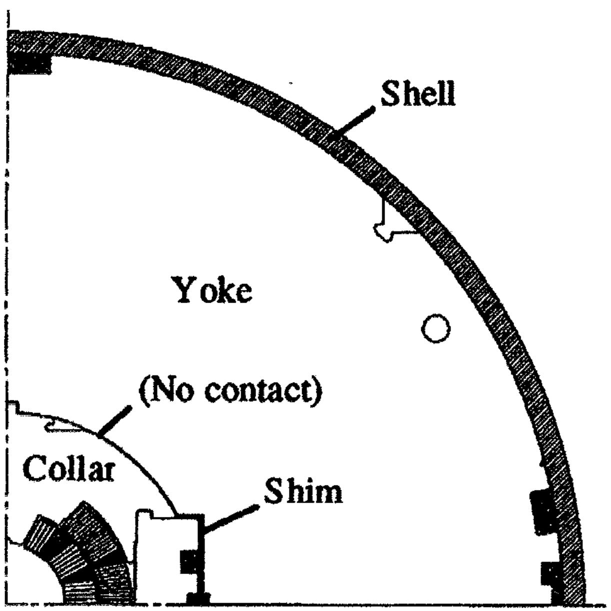

Fig. 1 Cross section of the model magnet in a quadrant. The five-block coil is collared with high-Mn steel, which is surrounded by horizontally split iron yoke. The shims between the collar and the yoke were removed to make a self-supporting condition by the collar itself.

MAIN PARAMETERS OF 56 MM APERTURE MODEL DIPOLE MAGNET

General			
Central field	[T]	8.65	
Operational current	[A]	11,537	
Coil inner radius	[mm]	28	
Collar outer radius	[mm]	89.5	
Yoke inner radius	[mm]	90.0	
Yoke outer radius	[mm]	260.0	
Magnet physical length	[mm]	1,200	
Length of straight s.s.	[mm]	800	
Yoke length	[mm]	600	
Outer cylinder thickness	[mm]	15	
Self inductance	[mH/m]	4.4	
Stored energy	[kJ/m]	290	
Magnetic forces ΣF_x	[kN/m]	1,800	
(1/4 coil) ΣF_y	[kN/m]	-160	
ΣF_z	[kN/m]	-690	
Coil		Inner	Outer
Number of turns		2 × 15	2 × 26
Coil peak field	[T]	9.0	7.6
Jo w/o insulation	[A/mm²]	407	523
Jo/Jc	[%]	~ 88	~ 85
Coil inner radius	[mm]	28.09	44.09
Coil outer radius	[mm]	43.09	59.09
Superconductor			
Cables			
Dimension Width	[mm]	15 + 0/-0.03	15 + 0/-0.03
Mid thick.	[mm]	1.89 ± 0.01	1.47 ± 0.01
Keystone angle	[°]	1.30 ± 0.05	1.00 ± 0.05
Number of strands		28	36
Twist pitch	[mm]	110 ± 5 (S)	95 ± 5 (Z)
Ic @ 1.9 K	[A]	> 13,750 @10 T	> 12,950 @9 T
Strand			
Superconductor		Nb-Ti/Cu	Nb-Ti/Cu
Strand diameter	[mm]	1.065 ± 0.003	0.825 ± 0.003
Cu/SC ratio		≥ 1.6	≥ 1.9
Filament diameter	[μm]	7 ± 0.5	7 ± 0.5
RRR of Cu		> 80	> 80
Twist pitch	[mm]	25 ± 3 (Z)	25 ± 3 (S)

SIS300: IHEP/GSI collaboration

Proceedings of EPAC 2004, Lucerne, Switzerland

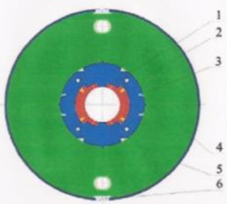

Fig.1. Design I: 1 – coil; 2 – collars; 3 – key; 4 – iron yoke; 5 – outer shell; 6 – staple.

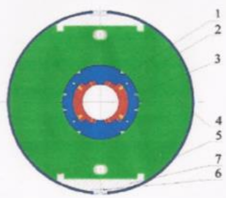

Fig.2. Design II: 1 – coil; 2 – collars; 3 – key; 4 – iron yoke; 5 – outer shell; 6 – staple; 7 – C-clamp.

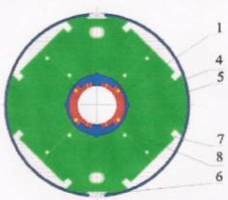

Fig.3. Design III: 1 – coil; 4 – iron yoke; 5 – outer shell; 6 – staple; 7 – C-clamp; 8 - spacer.

The main geometric characteristics of the three designs after optimisation are presented in Table 1.

value of central field with infinitely large magnetic permeability in the iron.

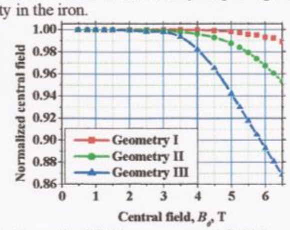

Fig. 4. Normalised field versus central field B_0.

The next three Figures demonstrate behaviour of lower integral field harmonics versus central field. The effects of superconductor magnetization were taken into account.

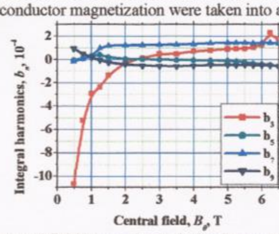

Fig. 5. Integral field harmonics in design I versus B_0.

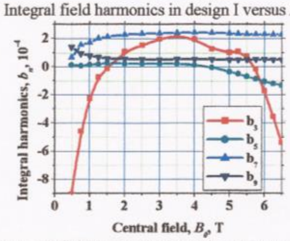

Fig. 6. Integral field harmonics in design II versus B_0.

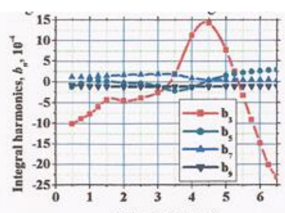

Fig. 7. Integral field harmonics in design III versus B_0.

The main geometric characteristics of the three designs after optimisation are presented in Table 1.

Table 1. Main Characteristics for Three Designs.

Geometry	I	II	III
Collar thickness, mm	45	30	10
Strand number in cable	38	35	30
Bare cable width, mm	12.80	11.70	9.91
Cable thickness with insulation, mm	1.264	1.273	1.289
Total turn number	91	90	89
Operating current, kA	4.98	4.78	4.48
Inner iron radius, mm	121.4	104.2	80.6
Iron thickness, mm	158	138	140
Coil length, mm	2750	2750	2750
Iron length, mm	2410	2434	2464
Length of cryostat, mm	3180	3180	3180

A single layer coil for the 6 T case

RHIC: Coil aperture - 80 mm; Central field: 3.5 T; coil temperature – 4.5 K

GSI001 model was constructed and tested based on the RHIC basis improved for fast ramped case

To reach 6 T we need operating current density about factor of 2 higher at 1.9 K and 7 T.
It was obtained: 2500 A/mm2 at 7 T and 2 K with NbTi/Ta (from Bochvar Research Institute)
Our calculations have shown that max. current density in the conductor should be not less of 900 A/mm2

Summary & Outlook

- R&D work on 6 T superconducting dipole aimed at the SPS future upgrade is started;

- Several options of SC magnets in the parameters range of B = 5 …7 T, dB/dt = 0.2 …4 T/s, were considered;

- The new solution: a single layer 6 T dipole is analyzing;

- We are planning to complete the conceptual design proposal by the end of 2017.

THANK YOU

FOR YOUR ATTENTION