SUPERCONDUCTING FAST-CYCLING DIPOLE MAGNETS FOR THE GSI FUTURE ACCELERATOR FACILITY

A.Kovalenko†, N.Agapov, S.Averichev, A.Doniagin, I.Eliseeva, I.Karpunina, H.Khodzhibagiyan, V.Kuzichev, G.Kuznetsov, A.Nesterov, P.Nikitaev, A.Starikov, L.Zaitsev, JINR, Dubna, Russia
G.Moritz, C.Muehle, E.Fischer, G.Hess, J.Kaugerts, M.Kauschke, GSI, Darmstadt, Germany

Abstract

The results of design and tests of 2T superconducting model dipoles, operating at 1Hz, are presented. The magnets use a SC coil made from hollow superconducting cable, cooled with forced flow two-phase helium, and utilise a two section window frame iron yoke at different temperatures: one section at 4.5 K, the other at 80 K. Measurements of magnet training, AC losses, and magnetic fields are presented. Some beam pipe design problems as well as radiation effects are also discussed.

1 INTRODUCTION

To reach high average intensities of 10^{12} U^{28+} and $2.5 \bullet 10^{13}$ protons per second at the proposed new GSI accelerator facility [1], a short cycling time, and thus a high magnetic field ramp rate of up to 4 T/s, is required for the dipoles. Up to now, only the magnets designed for the Nuclotron ring at JINR in Dubna [2] could provide this ramp rate, at magnetic field levels of up to 2 T.

The Nuclotron dipole magnet is based on a cold (4.5K) iron yoke of the window frame type, with a coil made from a hollow Nb-Ti composite cable, cooled with forced flow, two phase helium. This magnet design was taken as the basis by the GSI-JINR-collaboration, with the goals of improving the magnetic field homogeneity and substantially reducing AC power losses at 4.5K.

2 MODEL MAGNETS

The construction parameters of model magnets that have been manufactured during this R&D collaboration are listed in Table 1. The magnet named 4KDP1 is based on the standard Nuclotron design, while magnet 80KDP2 represents a new approach.

The cold mass of 80KDP2 (T=4.5K), consisting of SC winding and reinforcing shell, is separated from the iron yoke (T=80K) by a small vacuum gap. The cold mass is fixed inside the yoke by a support and alignment system. Investigation of such an approach was motivated by the problem of a large AC loss in the yoke of the Nuclotron dipoles (Q > 37W per 1.4 m magnet).

More detailed description of both 4KDP1 and 80KDP2 magnets as well as their first test results were presented at the MT-17 Conference [3,4].

† Email: kovalen@sunhe.jinr.ru
(telephone +7 096 21 65846)

Table 1: Model Magnets Parameters

	4KDP1	80KDP2
Aperture size (mm)	112x56	108x52
Magnetic induction (T)	2	2
Yoke length (mm)	1370	1370
Yoke size (mm)	292x205.5	292x203.4
Yoke gap size (mm)	146x56.4	153x59.6
Yoke temperature (K)	4.5	80
Mass at 80K (kg)	-	500
Mass at 4.5K (kg)	500	23
Cryostat diameter (m)	0.685	0.685
Winding		
Number of turns	16	16
Number of layer	2	2
SC cable length (m)	62	62
Cable		
Tube diameter (mm)	5	5
He channel diameter (mm)	4	4
External diameter (mm)	7	6.7
Number of strands	31	31
Strand diameter (mm)	0.5	0.5
Twist pitch of strands (mm)	47	47
Number of SC filaments	2970	2970
Filament diameter (μm)	6	6
Twist pitch of filaments (mm)	7	7

General view of the model magnet is presented in Fig.1.

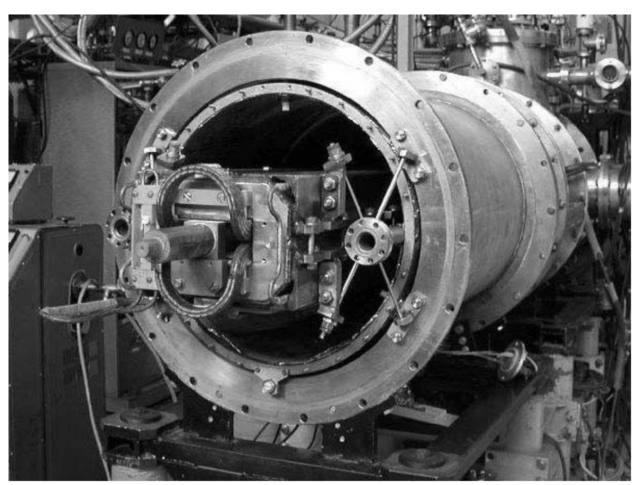

Figure 1: Model magnet on test stand.

3 EXPERIMENTAL RESULTS

The typical test program consisted of magnet training , AC magnetic field measurements, dynamic loss measurements (for cycles up to 2 T and different ramp rates up to 5 T/s), and static heat leak measurements (at zero current).

The results presented below are based on the experimental data obtained during September 2001 – April 2002. Each model magnet was tested twice.

3.1 Training

Fig.2 shows the training behaviour of 4KDP1. The quenches were measured at a ramp rate of 1 T/s. No ramp rate limitation of the quench current was observed up to 5 T/s. Note that the nominal operating current is 6000 A The critical current, at 2.7 T and 4.6 K is calculated (from wire short sample measurements) to be 8300 A.

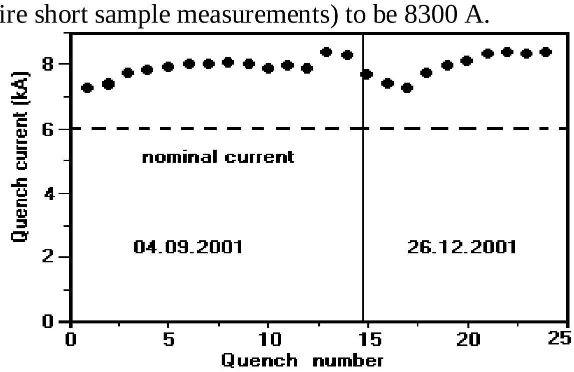

Figure 2: Training behaviour of 4KDP1 magnet.

The first quench in the winding of 80KDP2 was observed at I_c = 5690 A. The peak value of I_c = 7400 A was reached after two hours of training. Critical current I_m = 9400 A, calculated from the wire short sample measurements for 2.5 T and 4.5 K, was not achieved, most likely due to insufficient mechanical rigidity of the coil reinforcing shell. Nevertheless, after initial training, there were no quenches of 80KDP2 at operating current (I=6400 A).

3.2 Magnetic field

A measuring coil consisting of 3 parts, one central and two end parts, each with a 'bucking' coil (bucking ratio: 600) was used for the field measurements. Magnetic field harmonics up to n = 9 were measured with a relative accuracy of better than 10^{-4}.

The sum of the normal sextupole and decapole coefficients, in relative units at a reference radius of 25 mm and as a function of central field for the magnets 4KDP1 and 80KDP2 is presented in Fig.3. The field quality of 4KDP1 and 80KDP2 , especially at higher field levels, is better than that of the original Nuclotron magnet [3]. A spacer was also inserted between the two coil halves of 80 KDP2, to improve field quality.

The calculated integral field value of the ratio of sextupole to dipole field for 4KDP1 at 2 T and a radius of 25 mm, is $1.0 \bullet 10^{-3}$, while we measured $2.1 \bullet 10^{-3}$. The same quantity measured for 80KDP2 is $1.25 \bullet 10^{-3}$. Thus, the problem of improving the integral magnetic field at B = 2T still remains, for both model magnets.

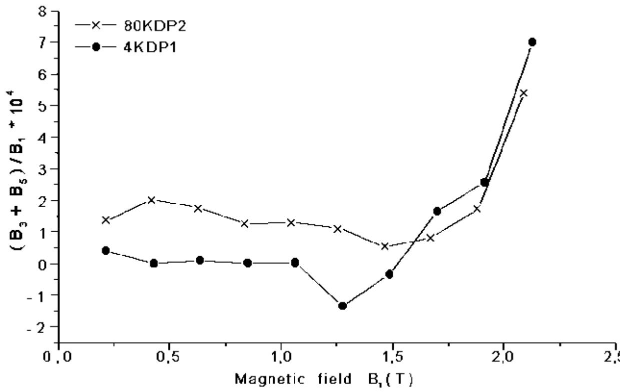

Figure 3: Comparison of the measured field qualities for the dipole 4KDP1 and 80KDP2.

3.3 Power losses at 4.5K

The measured power losses (W) at B=2T, dB/dt=4T/s, f = 1Hz, averaged over the tests are presented in Table 2.

Table 2: Measured Heat Releases to Helium

	4KDP1	**80KDP2**	**Nuclotron**
Total , W	53.0	25.3	59.6
in the yoke, W	>33	0	>37
in the coil, W	-	22.4	-
Static heat, W	4.8	2.8	6.6

Therefore, we have obtained good enough results for heat load reduction in 80KDP2, but not in 4KDP1. After detailed analysis of experimental data, it was decided to perform measurements of the temperature distribution along the magnet yoke. The modified magnet block 80KDP2 was used for that measurement. Both the yoke and the coil of 80KDP2 were cooled by helium flow through separate lines. Four temperature sensors were installed on the outer surface of the yoke at distances of 5 mm, 50 mm, 200 mm, and 700 mm from the yoke end, respectively. The experimental data obtained during March-April tests are presented in Fig. 4.

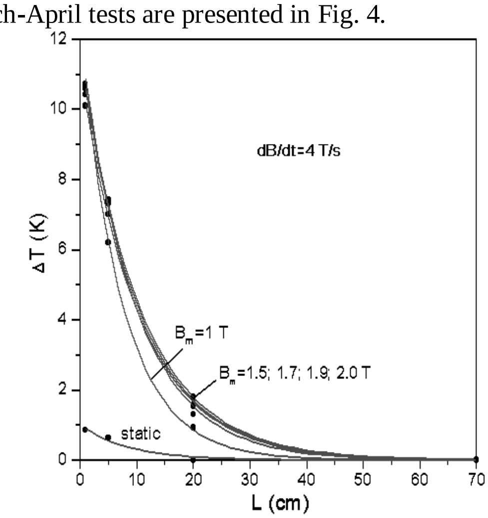

Figure 4: Distribution of the temperature difference between the middle and the end parts of the yoke.

As is clear from Fig.4, the main part of AC losses comes from the yoke ends. Therefore, special attention will be devoted to an optimisation of the yoke end design.

4 BEAM PIPE & VACUUM

The Nuclotron beam pipe was manufactured from a stainless steel tube with a wall thickness of δ_0 = 0.5 mm. Tubes of 0.75, 0.5 and 0.35 mm wall thickness were tested during the R&D stage. There is no dramatic increase of higher magnetic field harmonics if $\delta_0 \leq 0.5$ mm.

No separate helium cooling channels are used to cool the Nuclotron beam pipe. The power loss of about 5 W/m due to eddy currents is dissipated by SC-coil and cold iron yoke. The temperature of the beam pipe walls is about 25-30 K. The beam pipe vacuum is isolated from the magnet cryostat vacuum. The high vacuum pumping system of the Nuclotron ring consists of 12 sputter ion pumps and 9 cryosurfaces of about 0.4 m^2 each (cooled parts of a beam pipe 1 m in length each inside straight sections of the lattice), separated by about 31.4 m.

A preliminary analysis of beam pipe requirements has been performed for the case of SIS 100. To minimize heat losses requires the use of a stainless steel tube 0.2-0.3 mm in thickness. The required pumping can be provided by the cold (T=4.5K) surfaces (cryopumps) installed at the ends of the dipoles. Non-evaporable getter material can be used to increase H_2 molecular pumping efficiency.

The other options of the beam pipe are also considered (ceramic pipe, thin foil screen etc.). The work on optimization is in a progress.

5 RADIATION & MAGNETS RESOURCE

The estimated maximum radiation dose D_{lim} (G_y) for the Nuclotron magnet is presented in Fig.5. Radiation tolerance of some insulation materials is also presented on this plot. Note that the dose power is quite different for the main part of the magnets (D_{reg}) and for those which are installed near the beam extraction system (D_{extr}) [5]. The data expected for SIS100, scaled to N=10^{12} p.p.s, and U^{28+} extraction efficiency of 99% are marked by "I" and "II" in Fig. 5.

Assuming 6000 hours of annual operation for SIS100 during its 20 year lifetime, it is possible to conclude that the coils of most of the magnets will not lose their mechanical stability. Nevertheless, it's quite clear that inorganic insulation materials should be used for 2-3 magnets placed near a "hot" radiation zone. As Fig. 5 shows, the most critical component of the magnet coil is the epoxy. There are no reliable experimental data regarding radiation hardness of epoxy, in the case of low absorbed dose power D=10^{-3}-$10^{-2}$$G_y$/s. It seems reasonable further tests of the magnet coil glued with polymer cement composite or mixture of epoxy and polymer cement. Finally, it should be noted that the problem of long-term radiation stability of SIS100 magnets in a "hot" zone exists for both superconducting and conventional warm magnet options.

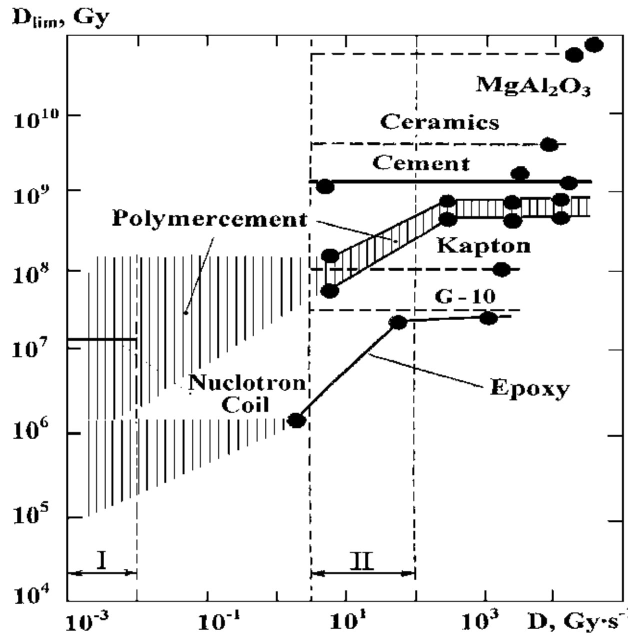

Figure 5: Radiation dose corresponding 25% loss of the yield strength: • - experiments; ||||||||| -.preliminary simulation [6].

5 SUMMARY & OUTLOOK

Experimental data have been obtained during tests of both 4KDP1 and 80KDP2 model magnets at LHE JINR. These tests, as well as more detailed computer simulations at GSI, provide evidence of the construction feasibly of a superferric dipole magnet with AC power loss of 12 W/m, at B=2T, dB/dt=4T/s, f=1 Hz, and magnetic field nonlinearity of $\pm 2 \cdot 10^{-4}$ within the aperture radius R ≈ 25 mm. As the next steps, we are planning to test a model magnet with modified iron yoke end parts, as well as to construct model magnet 80KDP3, which will have a more rigid cold mass.

6 REFERENCES

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