APPLICATION OF THE SUPERCONDUCTING TRANSMISSION LINE TO ACCELERATOR MAGNET DESIGN

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Abstract

The magnetic elements with warm iron yoke and linear superconducting (SC) excitation current coils (transmission line) have been designed. The numerical simulations of the magnet parameters (iron yoke, pole profile and field distribution) have been done. Applications of such an economical magnets in synchrotrons, transport beam systems and undulators are presented.

INTRODUCTION

In Laboratory of High Energies, JINR the certain experience in development and creation of the magnets with the cold yokes and SC excitation coils has been accumulated [1]. These are so-called window-frame type magnets with tube winding carring the two phase helium flow. Such a magnets show the high reliability during Nuclotron runs.

The essential increase of the Nuclotron beam intensity is connected to the substantial growth of the injection energy. For this purpose it is necessary to have fast cycling booster with a large aperture to realize the problem of multi-turn injection and storage. The total power consumption of the Nuclotron extracted beam transport lines is comparable to consumption of the main ring. Therefore the use of SC magnetic elements for beam transportaion becomes quite actual.

For different applications in accelerator technique C-type combined function magnets have been developed. The specific feature of such a magnets is the SC exitation current coil - transmission line [2]. The transmission line excites the magnetic field, the warm iron yoke (pole profile) shapes the distribution of the magnetic field in beam aperture both for bending and for focusing. The development of C-type magnets for synchrotrons, beam transport lines, undulators is presented.

TRANSMISSION LINE

The linear SC excitation current coil - transmission line includes the several hollow cables developed for the Nuclotron magnets [1]. The assemble view of the SC cable is given in Fig. 1. The 5*0.5 mm^2 copper-nickel tube is wraped up by the 31 SC wires 0.5 mm in diameter having the 1045 SC NbTi 10 μm filaments. The tube is covered by the insulation and nichrom wire band. The critical current of SC cable in the field of 2.5 T is 6.8 kA. The maximum operation voltage of insulation is 2.5 kV. The minimum bending radius is 18-20 mm. The cable has the high mechanical strength and stable to radiation up to 5×10^6 Gr.

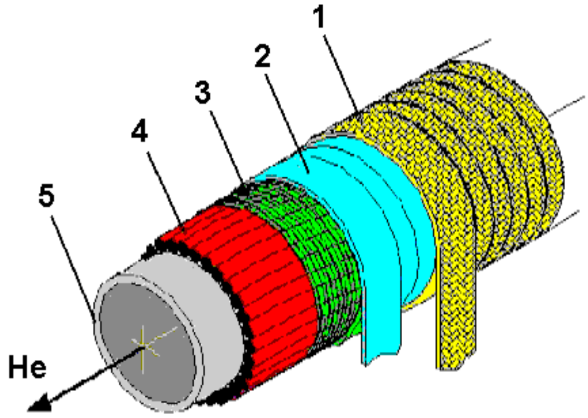

Figure 1: Nuclotron superconducting cable: 1 – glass-fiber tape, 2 – kapton tape, 3 – nichrom wire, 4 – superconducting wire, 5 – copper-nickel tube.

It is not efficient to use the very high excitation current in separate magnets of the transport beam lines because of the large number of SC current inlets. Beam transport system does not require the pulse operation mode. Then the DC SC magnets for that purpose were proposed. The electrically insulated SC wires are connected successively to form the winding with 200 A DC . The transmission line is designed following the standart of the long cryogenic systems technology "pipe in pipe" [3]. The screen vacuum insulation decreases the heat flow from the room temperature region to the SC cables. The magnet coil consists of 7 superconducting cables (Fig. 1). The transmission line coil is placed inside a stainless pipe 21 mm in diameter and 0.5 mm in thickness. The screen-vacuum insulation of the coil pipe is made of 30 layers of 12 μm aluminized lavsan. The cable tube is mounted on the insulation support in the vacuum jacket. From the estimation, the heat leak to the superconducting lines is about 3 W/m.

MAGNET DESIGN

The numerical calculation of the C-type transmission line magnets has been carried out. The optimizations of

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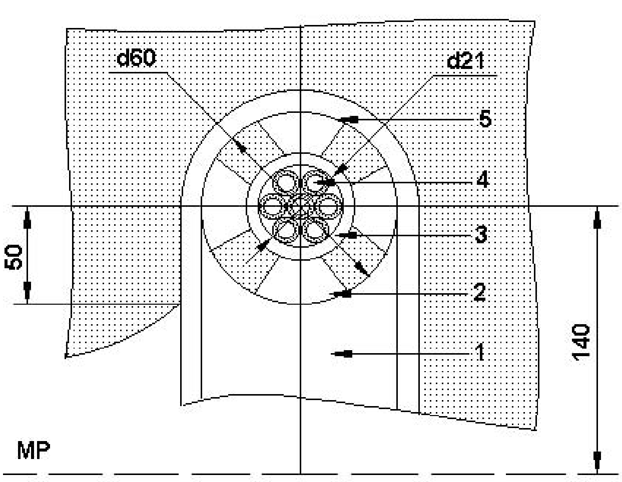

Figure 2: Superconducting coil for double transmission line magnet: 1 – coil support, 2 – insulating coil support, 3 – screen vacuum insulation, 4 – cables, 5 – vacuum jacket, MP – median plane.

the yoke and pole profiles, field distribution, parameters of the SC line and mechanical strength have been considered for 1 and 2 line magnets (10 and 7 SC cables in each line). The magnets provide the peak guiding field of 1.2 T and field gradient of 4.5 T/m. The forces in transmission line are $F_{x,y} = 3/0; 0.1/0.8$ t/m correspondingly. The cross-sections of the magnets are shown in Fig. 3, 4.

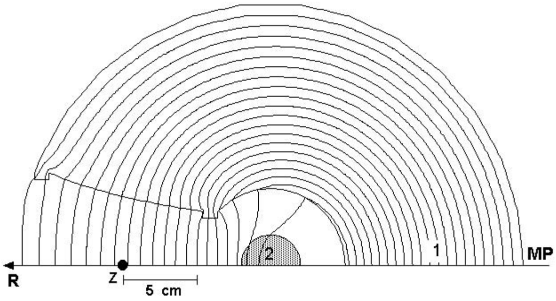

Figure 3: Defocusing transmission line magnet with 1 coil: 1 – iron yoke, 2 – superconducting coil, MP – median plane, Z – reference beam axis. Equipotential lines of the magnetic field are shown.

BOOSTER SYNCHROTRON

The magnetic field shaping is more effectivelly realized for 2 line magnet. This magnet was chosen for Nuclotron booster [3]. The main parameters of F and D magnets are given in Table 1. 63 m synchrotron includes 8 superperiods. Each of them consists of three doublets of combined function C-type magnets and one straight section. A drifts are used to install acceleration, injection, fast and slow extraction systems. The F and D magnet gaps are faced outside the ring for easier injection and extraction. The developed magnets allow to build the fast cycling, compact and economic synchrotron with the energy up to 500 MeV/u.

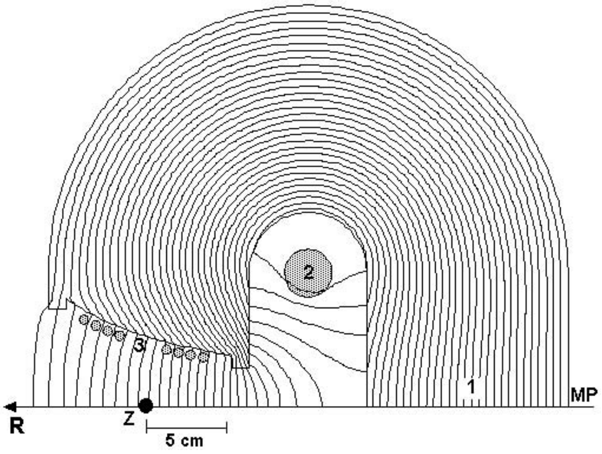

Figure 4: Defocusing magnet with 2 superconducting line coils and warm correction coils: 1 – iron yoke, 2 – superconducting coil, 3 – correction coils.

It could be used for multi-turn injection and storage in Nuclotron and also for scientific and applied investigations like radiotherapy with 450 MeV/u carbon beams [4]. General synchrotron parameters are presented in Table 2.

Table 1: Parameters of F and D magnets

Length	1.0 m	N coils	2
Dipole field	0.9 T	N cables	7*2
Field gradient	4.5 T/m	Amp.turns	2*42 kA
Deflect. angle	7.5 grad	Current	6 kA
Bending radius	7.6 m	Energy	8 kJ
Aperture	10*6cm^2	Inductance	0.5 mH
SC cable diam.	7 mm	Weight	700 kg

Table 2: General synchrotron parameters

E:p inj/max	20/1200 MeV	Repetition	5 Hz
ions,A/Z=2	5/450 MeV/u	N super.	8
$B\rho$ inj/max	0.6/6.7 Tm	N FD/drf	24/8
Perimeter	62.88 m	N mag.	48
L mag/drift	1/1.86 m	R bend.	7.6 m
B inj/max	0.085/0.88 T	Q'_x/Q'_y	-0.7/-2.4
G inj/max	0.4/4.2 T/m	$\beta_{x,y}$ max	9.2 m
$A_{x,y}$ $\pi\mu\mathrm{m}$	400/250	D_x max	2.6 m
$\varepsilon_{x,y}$ inj/min	50/45;5/4	Comp.fact.	0.2
Q_x/Q_y	2.4/2.45	$\Delta p/p$	±0.001

BEAM TRANSPORT SYSTEM

The wide distributed transport system of the Nuclotron extracted beams is based on the warm magnetic elements. Then the several experiments go in parallel the power consumption overcomes the Nuclotron ring consumption. There are two ways to solve the problem: removing the old transport system by SC elements - dipoles and quadrupoles with transmission line [3]; removing only the coils of the existing elements by SC ones. Now the real way is to replace the old winding with 200-250 A DC SC coils. The new technology of SC cables should reduce the power considerebly.

UNDULATOR SYSTEM

The transmission line technology could be succesfully used in FEL systems based on undulators - devices with the periodic magnetic field distribution: $B = B_0 * \cos(2\pi * z/\lambda_u)$, where λ_u - period length of magnetic structure, B_0 - magnetic field amplitude. The energy of the electron bunch going in undulator is transformed into photon energy. The generated wavelength can be presented as $\lambda = \lambda_u * K^2/4\gamma^2$, where γ - relativistic factor, $K = 93.4 * B_0[\mathrm{T}] * \lambda_u[\mathrm{m}]$ - undulator factor.

For a wide range of FEL researches the wavelength variation is desirable. The possibilities to adjust wavelength are beam energy scanning, variation of the magnetic field and changing of the undulator periodicity. The permanent magnet undulator provides the short period λ_u and easier mechanical alingment. But long undulator systems require the big volume of the magnetic material and become very expensive. The electromagnetic undulator with SC transmission line is serious alternative to permanent magnet device. In Fig. 5 the proposed design of 2 line undulator [5] is shown. The total current of 6 kA in 7 cable SC transmission line produces the peak field of 0.6 T (Fig. 6). With the beam energy of 800 MeV and undulator period of 0.28 m the radiation wavelength is 7 μm.

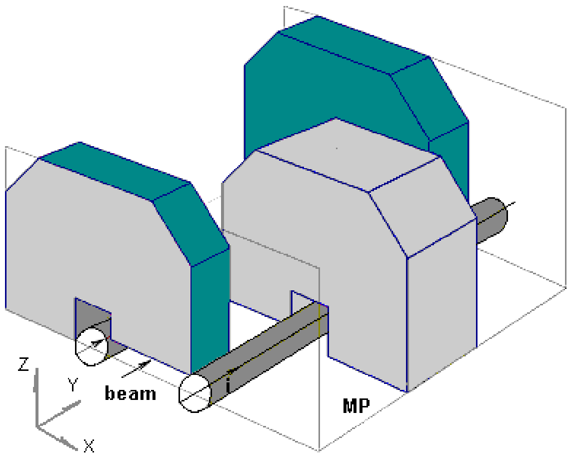

Figure 5: Scheme of the undulator period (upper part).

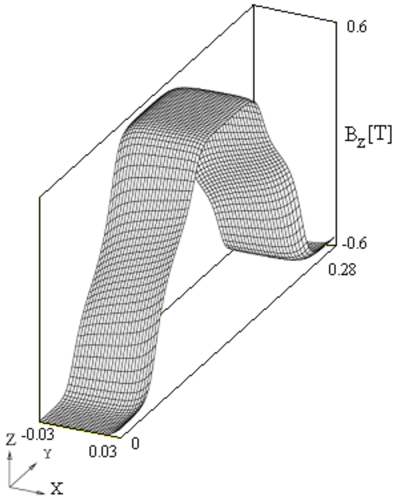

Figure 6: Magnetic field distribution in undulator median plane over beam excursion period.

CONCLUSION

The superconducting linear transmission line coil has the easier way of cryostating and provides the new and wide possibilities for development of the efficient SC magnetic systems for synchrotrons, beam transport lines, undulators, electrotransfer lines.

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