DESIGN OF HTS SECTOR MAGNETS FOR THE RCNP NEW INJECTOR CYCLOTRON

Kichiji Hatanaka*, Mitsuhiro Fukuda, Tetsuhiko Yorita, Hiroshi Ueda, Hitoshi Tamura, Mitsuru Kibayashi, Keichi Nagayama, Yuusuke Yasuda, Takane Saito, Shunpei Morinobu, and Nobuhiko Izumi
Research Center for Nuclear Physics, Osaka University, 10-1 Mihogaoka, Ibaraki, Osaka, 567-0047
Takeo Kawaguchi
KT-Science, 1470-1-803, Fujie, Akashi, Hyogo, 673-0044

Abstract

The RCNP cyclotron cascade system consists of K140 AVF cyclotron and K400 ring cyclotron and is providing high quality beams for various experiments. There are increasing demands for high intensity beams and even to improve the quality. In order to increase the physics research opportunities, a new injector cyclotron is recently proposed, which has four separated sector magnets and two accelerating cavities. Sector magnets are designed to use High Temperature Superconducting (HTS) wire. At RCNP we have been developing magnets with HTS wires for a decade. In this paper, we will report recent results of developed HTS magnets and the design of sector magnets for the new injector SSC.

INTRODUCTION

The Research Center for Nuclear Physics (RCNP) is a national user's facility founded in 1971 and is the major research institute for nuclear physics in Japan. The cyclotron facility is its major facility and consists of an accelerator cascade and sophisticated experimental apparatuses. Research programs cover both pure science and applications. Demands for industrial applications have been growing more and more. A schematic layout of the RCNP cyclotron facility is shown in Fig. 1. The accelerator cascade consists of an injector Azimuthally Varying Field (AVF) cyclotron (K=140) and a ring cyclotron (K=400). It provides ultra-high-quality beams and moderately high-intensity beams for a wide range of research in nuclear physics, fundamental physics, applications, and interdisciplinary fields. The maximum energy of protons and heavy ions are 400 and 100 MeV/u, respectively. Such ultra-high-resolution measurements as $\Delta E/E=5\times10^{-5}$ are routinely performed with the Grand-Raiden spectrometer by utilizing the dispersion matching technique. Recently a super-thermal ultra cold neutron (UCN) source and a muon production source (MUSIC) have been constructed and high intensity beams are strongly required.,

In order to supply both high quality primary beams and high intensity secondary particles, neutrons and muons, we have proposed a new injector to replace the existing AVF cyclotron. The injector consists of a 200 kV high voltage platform, an energy variable radio-frequency quadrupole (RFQ) linear accelerator and a separated sector cyclotron (SSC). We plan to apply high-temperature superconducting (HTS) wire for main coils of the SSC. We have been developing mgnets utilizing HTS wire for a decade.

In this paper, some results of our HTS magnet developments and design studies on SSC coil are described.

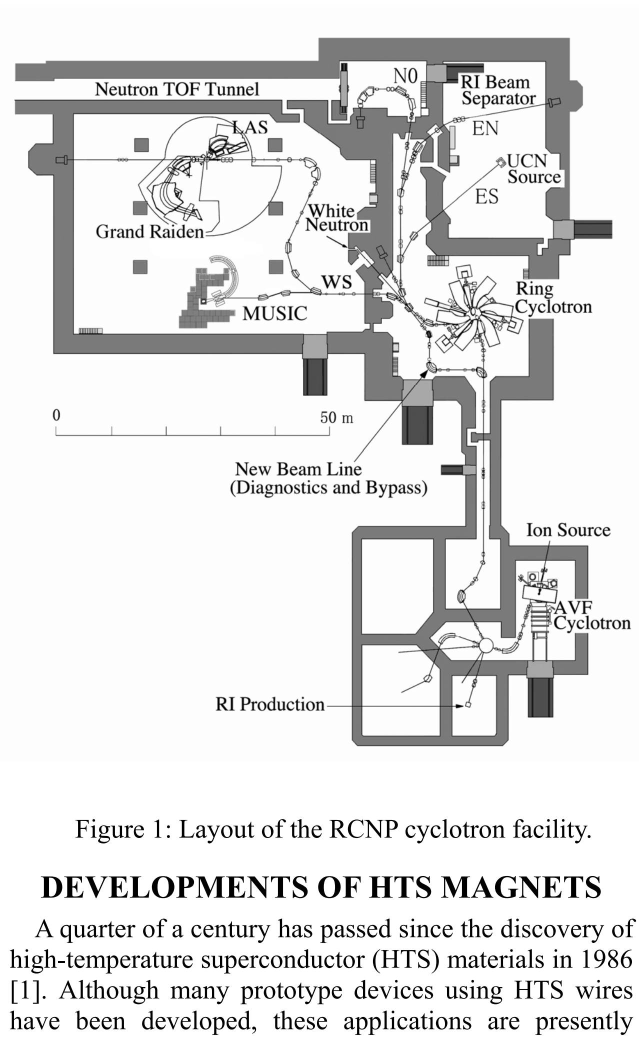

Figure 1: Layout of the RCNP cyclotron facility.

DEVELOPMENTS OF HTS MAGNETS

A quarter of a century has passed since the discovery of high-temperature superconductor (HTS) materials in 1986 [1]. Although many prototype devices using HTS wires have been developed, these applications are presently rather limited in accelerator and beam line facilities [2]. We stated to investigate the performance of HTS wires applied for magnets excited by alternating current (AC) as well as direct current (DC) a decade ago.

* hatanaka@rcnp.osaka-u.ac.jp

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Our initial study demonstrated a possibility to excite HTS magnets with alternating currents (AC) [3]. Since HTS systems have higher operating temperatures than low-temperature superconductor (LTS) systems, the cryogenic components for cooling are simpler and the cooling power of refrigerators is much larger than at 4K. Because the temperature range for superconductivity is wider than for LTS systems, a larger range of operating temperatures is available. A high-frequency AC mode operation should be possible in spite of heating loads due to AC losses in the coils. A two-dimensional scanning magnet was designed to model a compact beam scanning system and to investigate AC losses in operation. Several AC loss components are observed in both LTS and HTS magnets [4, 5]. They are (1) hysteretic magnetization losses in the superconductor material, (2) dynamic resistance losses generated by a flux motion in the conductor, (3) coupling losses through the matrix, and (4) eddy current losses in the matrix and metallic structures including cooling plates. For HTS magnets, there are Ohmic losses at exciting currents above the critical current as well. Each AC loss shows a different dependence on the frequencies (f), the amplitude of the external magnetic field (B) and the transport current (I_t).

Figure 2 shows the measured AC power losses of a pair of oils in series [6] Observed dissipated powers per cycle (open symbols) are almost independent of the frequency of the transport current The solid curve in the figure shows the theoretical hysteretic magnetization loss which is normalized to the measured value at 45A and 15Hz. At 20K, J_c of the present HTS wire is about 5 x 10^8A/m^2. The theory is found to reproduce the scaling law well as a function of the transport current, if we take account the temperature dependence of the critical current density of the conductors. For the application, the total dissipated power may be too large to be removed by a GM (Gifford-McMahon) refrigerator. It is strongly expected to develop low AC loss wires in near future.

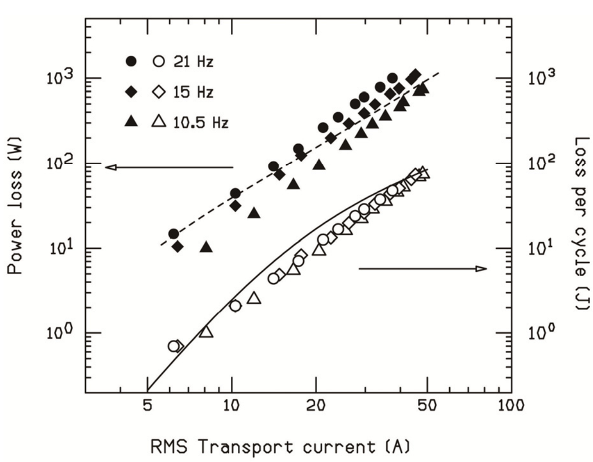

Figure 2: Measured AC losses at 20K of the B_x coils in series. Full symbols show the total power losses on the left side scale. Open symbols present losses per cycle on the right side scale. The solid curve is a theoretical prediction normalized to the measured data.

Table 1: Design Parameters of the 3T Dipole Magnet

Magnet	Bending radius Bending angle Gap	400 mm 60 deg. 30 mm
Coils	Number of turns Winding Temperature Rated current	600x2 3 Double Pancakes / coil 20 K 300 A

In order to investigate feasibilities of synchrotron magnets using HTS wire, we are fabricating a super-ferric dipole magnet to be operated by lumping currents. Specifications are summarized in Table 1. Upper and lower coil consists of 3 double pancakes of 200 turns. Critical currents were measured of wire measured at 77K. Self-field Ic of wire was higher than 160A. Ic values of double pancakes were 60-70A. After stacking, they were 47A and 51A for the upper and lower coil, respectively. There were no damages in wire during winding process. Figure 3 shows the assembled magnet. Coils have a negative curvature and are fixed to cold poles to bare the radial expansion force of 100,000 N/m. Performance tests will be started this fall.

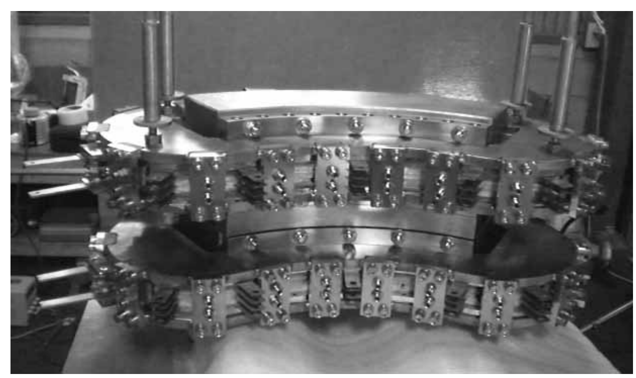

Figure 3: Assembled 3T dipole magnet

HTS SECTOR MAGNETS

Specifications of the proposed SSC are summarized in Table 2. The frequency range of the accelerating voltage is same as that for the RCNP ring cyclotron. The K-value is 120 MeV. The cyclotron consists of four sector magnets. and each pole width is 33 deg. The SSC will be installed in the existing building and the height of the sector magnet must be lower than 5 m. In order to avoid irons to saturate, the width of upper and lower yokes are increased to 50 deg. Figure 4 and 5 shows the horizontal and vertical section of a sector magnet, respectively. There are two double-gaps accelerating cavities and the angle between gaps is 17 deg. The harmonic number of 9 and 15 are applied. The effective RF width of the electrode is 134 and 224 deg, for the harmonic acceleration of 9 and 15, respectively. The effective acceleration voltage is larger than 90% of the RF peak voltage.

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Table 2: Specifications of the Injector SSC

Number of sectors	4
K-value	120 MeV
Maximum injection voltage	900 kV/q
Injection radius	371 mm
Extraction radius	3,000 mm
RF frequency	30-52 MHz
Harmonic number	9,15
Pole width	33°
Yoke width	50°
Height of a sector magnet	2,800 mm

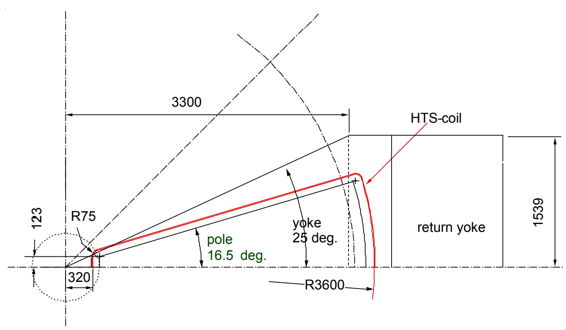

Figure 4: Horizontal section of a sector magnet.

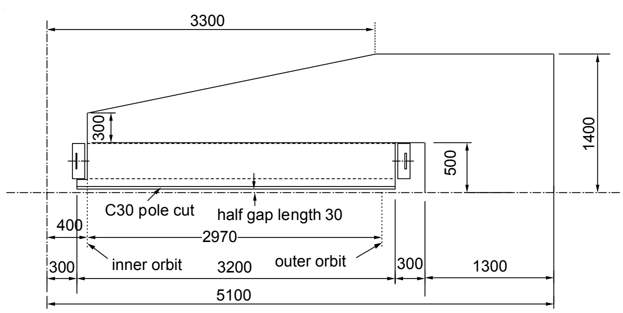

Figure 5: Vertical section of a sector magnet.

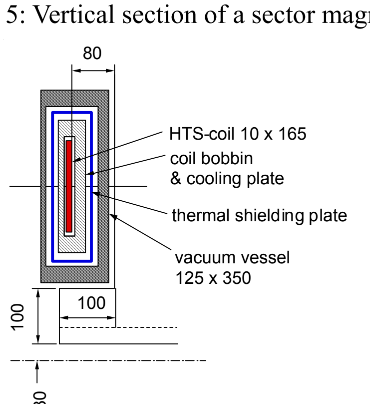

Figure 6: Cross section of a cryostat.

The cross section of a cryostat is shown in Fig. 6. The magnetic field is calculated by the code TOSCA. Table 3 summarize field strengths at the total current of 50 kA, which are enough for the K-value of 120 MeV. Normal conductors are applied for trim coils.

Table 3: Magnetic Field on Circle Orbits at 50 kA

Radius (m)	Integrated Bz (Tm)	Orbit length (m)	Average Bz (T)
0.4	0.178	0.314	0.568
1.885	0.793	1.48	0.536
3.37	1.39	2.65	0.526

This work was supported in part by the Grant-in-Aid for Scientific Research No. 18390334 and 20249056 of the ministry of Education, Culture, Sports, Science and Technology of Japan.

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