Development of Cryoundulators

Introduction

Short period undulators are an attractive light source for synchrotron radiation facilities. Since a short periodicity increases the number of undulator periods in a limited space of straight sections, higher brilliance can be obtained for undulator radiation. Also, short undulator periodicity enables the emission of high energy photons and opens the way for X-ray beamline operation in medium size facilities [1,2].

As the undulator periodic length decreases, the dimensions of the magnet pieces become smaller, and consequently, the undulator should be operated at small magnetic gaps in order to obtain sufficient magnetic fields. From this aspect, in-vacuum undulators, which accommodate permanent magnet arrays inside a vacuum chamber, are indispensable for the realization of short period undulators [3,4]. One example of an in-vacuum short-period undulator is the 11-mm-period undulator developed by collaboration between SPring-8 and NSLS. This undulator has been successfully operated at the gap of 3.3 mm for years in the NSLS storage ring [2]. However, this device has a blank region in its radiation spectrum which neither fundamental nor higher harmonics can cover, which is a drawback for some user experiments. The practical limit to the minimum undulator gap is determined by the effect to the electron beam. If the gap is too small, there is not only a reduction in beam lifetime, but also the possibility of demagnetization of the undulator magnets.

To solve these problems and realize shorter undulator period, high performance magnets are required. One prospective technology is superconducting magnets, which have been widely used as wigglers. Unlike wigglers, superconducting undulators operated at small gaps should endure a larger amount of heat load due to resistive wall effects of electron beams and synchrotron radiation from upstream bending magnets. However, superconducting devices are normally operated at around the temperature of liquid helium and the cooling capacity is limited to a few watts. Therefore careful consideration should be paid to this thermal budget problem, otherwise the device will be easily quenched [5].

At SPring-8, we are developing a new device for improving the undulator magnetic field performance, which we call the cryoundulator, using permanent magnets at the temperature of liquid nitrogen or higher, where a cryocooler of a few hundreds watts is easily achievable with the current technology [6,7].

Characteristics of permanent magnets at cryogenic temperatures

The permanent magnets used in the SPring-8 undulators are NdFeB magnets having the highest magnetic field performance among permanent magnet materials. Although there is a variety of NdFeB magnets, a magnet with sufficiently high coercivity (iHc) should be chosen for the in-vacuum undulator to ensure good field stability against demagnetization due to electron beam irradiation [8]. In general, NdFeB magnets with high iHc show small remanent field (Br). Therefore, the in-vacuum undulators do not take advantage of the highest magnetic field of NdFeB magnets. However, under the circumference of cryogenic temperatures, both iHc and Br increase with decreasing temperature, and high Br NdFeB magnets come to have sufficiently high iHc for the undulator magnet. This is the basic concept of the cryoundulator.

Figure 1 shows the measured Br and iHc of two NdFeB magnets as a function of temperature. 35EH is the magnet currently used in the SPring-8 in-vacuum undulators and 50BH is a typical high Br magnet. Both magnets show the highest magnetic field (Br) at temperatures around 140~150 K, and their iHc increases inversely proportional to the temperature. From Fig.1 (b), it is inferred that iHc of 50BH at 150 K (~3000 kA/m) exceeds the room temperature iHc of 35EH (~2000 kA/m). This means that the high Br magnet (50BH) at low temperature is more stable than the room temperature magnet (35EH) used for current in-vacuum undulators [9]. This high Br magnet (50BH) is one of the candidate materials for the cryoundulator. Compared with conventional in-vacuum undulators, the expected magnetic field of the cryoundulator is superior by about 30% with better demagnetization characteristics.

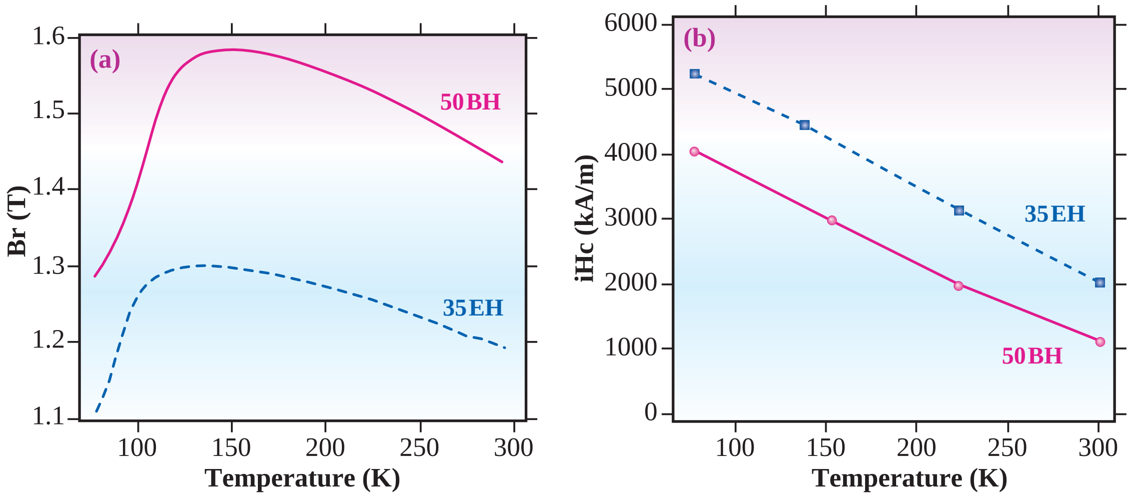

Fig. 1. Measured remanent fields Br **(a)** and coercivity iHc **(b)** of NdFeB magnets at cryogenic temperatures. 35EH is the magnet used in the SPring-8 in-vacuum undulators and 50 BH is a typical high Br magnet. 35EH and 50 BH are commercial products of NEOMAX Co., Ltd.

Prototype undulator

The construction of the cryoundulator requires only slight modification of the conventional in-vacuum undulators, since the magnet arrays are already placed under good thermal isolation with vacuum. A design example of the cryoundulator is shown in Fig. 2, where thermal insulation is enforced at the magnet supports and the undulator magnets are cooled by cryocoolers. A compact Gifford McMahon type cyocooler can provide sufficient cooling capacity of a few hundreds watts around the temperature of liquid nitrogen. The expected heat load of a 1.5-m-long undulator, for example, is about 130 W at the gap of 3 mm, assuming operation in SPring-8 in the 203 bunch mode.

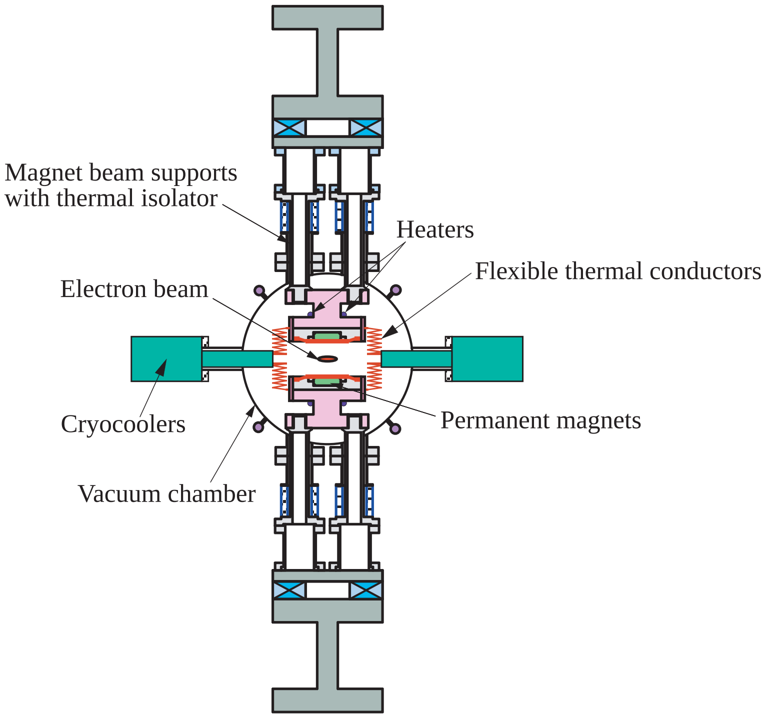

Fig. 2. Design example of the cryoundulator.

Figure 3 is a prototype cryoundulator under development at SPring-8, whose period is 15 mm. Using heaters, the temperature of the magnets is controlled to be the optimum temperature, at which the highest magnetic field can be obtained. Preliminary results of the magnetic field measurements show that the magnetic field errors do not depend on the temperature. This means that once the undulator field is aligned at room temperature, realignment at low temperatures is not necessary, which simplifies the procedure of undulator construction. Detailed field measurements are currently being carried out on this prototype undulator.

The cryoundulators will play an important role as a synchrotron radiation source, particularly in medium size facilities. They are also attractive for SASE-FEL facilities, since they lower the electron beam energy necessary for X-ray FEL operation, resulting in the reduction of the facility size [10]. Unlike superconducting devices, there is no worry concerning the quenching and thermal budget problem. Therefore, stable operation can be expected for the cryoundulators.

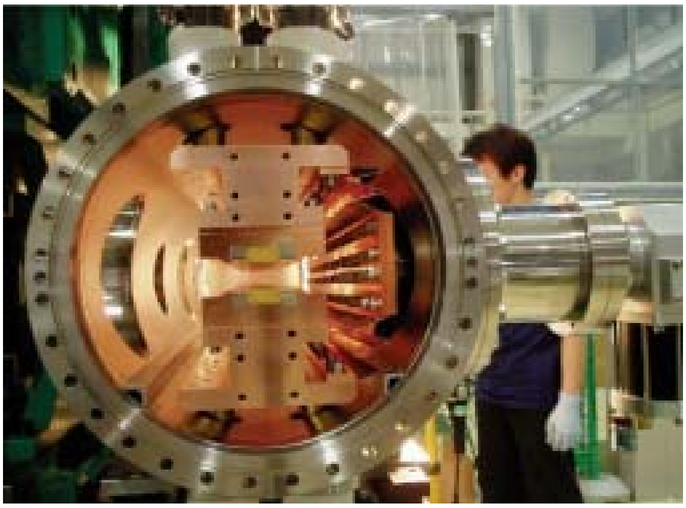

Fig. 3. Prototype of the cryoundulator developed at SPring-8. The undulator period is 15 mm and 50BH NdFeB magnets are used.

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