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Magnetic Field Stability of PrFeB Magnets Developed by GBD for Cryogenic Permanent Magnet Undulators

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Abstract: The magnetic field stability of the PrFeB magnetsis one of the key points which affect its applicationin such devices as cryogenic permanent magnet undulators. In this study, the magnetic properties and microstructure of PrFeB magnets, which were developed by the grain boundary diffusion, were examined. The demagnetizing field distribution of the cryogenic permanent magnet undulator made using the PrFeB magnets was simulated by Radia, and the change mechanism of the irreversible demagnetization following treatments at high temperatures was experimentally studied. The results show that the intrinsic coercivity of the PrFeB magnets can be increased by diffusion of Tb. Meanwhile, the remanence of the magnets displays almost no loss, and the increasing range is closely related to the orientation thickness of the PrFeB magnet. Therefore, the PrFeB magnets developed using grain boundary diffusion are found to have extremely high comprehensive magnetic properties. The irreversible demagnetization of the PrFeB magnets developed by Grain Boundary Diffusion for the CPMU is determined to be significantly improved following high-temperature treatments.

Keywords: PrFeB; Grain Boundary Diffusion; undulator; irreversible demagnetization

1. Introduction

Undulators are the key equipment for synchrotron radiation facilities and free electron lasers[1,2,3]. The NdFeB are currently one of the main magnetic field sources for undulators[4,5], and the crystal structures of the PrFeB are similar to the NdFeB. Also, their theoretical remanence (B_r) and intrinsic coercivity (H_{cj}) are similar at room temperature. However, the PrFeB have excellent cryogenic magnetic properties for no spin reorientation(SRT), which makes them more suitable as a magnetic field sources for a cryogenic permanent magnet undulators (CPMU)[3,6]. In recent years, Spring-8 of Japan, ESRF of Europe, and SSRF of China have completed some research studies regarding the magnetic properties of the PrFeB[7,8,9,10]. The operating temperature of the CPMU is approximately between 10 and 80 K, which means the PrFeB have a very high H_{cj} at cryogenic temperatures, and thereby have good low temperature magnetic field stability. However, the magnetic field stability of the PrFeB magnets at the room and higher temperatures has been found to be very poor. This is one of the key problems affecting their applications for CPMU. The main reasons for this instability are as follows：

1) The manufacturing method for the PrFeB magnets is not yet mature, there are many reverse magnetic domains in the magnets which make them more likely to demagnetize at higher temperatures;

2) The temperature coefficients of the PrFeB are much larger than those of the NdFeB and SmCo;

3) The short cycle magnet design of the CPMU, which makes the working points of the PrFeB magnets is close to safety point H_k[3];

4) The CPMU will usually be installed at room temperature, which causes the PrFeB magnets to be required to withstand a large reversed magnetic field;

5) In order to achieve the ultra-high vacuum of the CPMU, it is the often required that the PrFeB magnets have less irreversible magnetic field loss under the high-temperature conditions for the removal of the surface residual gas from the magnet, while the H_{cj} of the PrFeB magnets has been found to be significantly reduced in high-temperature environments.

The magnetic field stability of the PrFeB magnet is closely related to the H_{cj}[5]. The increasing H_{cj} can improve the magnetic field stability of the CPMU made with the PrFeB magnets. At the same time, the irreversible demagnetization experimental data are also very important for the development of the CPMU. The H_{cj} and the B_r of the PrFeB magnets are contradictory concepts. A higher H_{cj} means significantly reduced B_r by traditional powder metallurgy preparation method[5]. A grain boundary regulation is an effective method to improve the comprehensive magnetic properties of rare earths permanent magnets[11,12]. Also, the H_{cj} can be greatly improved without reducing the B_r of magnets by saving valuable Dy/Tb using a Grain Boundary Diffusion (GBD)[13,14,15]. In this study, a GBD method was used to prepare the PrFeB permanent magnets with extremely high comprehensive magnetic properties. The magnetic property change mechanism of the PrFeB magnets and the irreversible demagnetization of the CPMU20 made with the PrFeB magnet developed by GBD were examined in depth in this study.

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