World's First Persistent Current Operation of High-performance Iron-based Superconducting Joints

Yanchang Zhu[1,2,3], Dongliang Wang[1,2,3], Qiqi Wang[4], Zhan Zhang[4], Wenwen Guo[1,2], He Huang[1,2,3], Hongjun Ma[4], Fang Liu[4], Huajun Liu[4] and Yanwei Ma[1,2,3,*]

[1] Key Laboratory of Applied Superconductivity, Institute of Electrical Engineering, Chinese Academy of Sciences, Beijing 100190, People's Republic of China

[2] University of Chinese Academy of Sciences, Beijing 100049, People's Republic of China

[3] Institute of Electrical Engineering and Advanced Electromagnetic Drive Technology, Qilu Zhongke, Jinan 250013, People's Republic of China

[4] Institute of Plasma Physics, Chinese Academy of Sciences, Hefei 230031, People's Republic of China

[*]E -mail: ywma@mail.iee.ac.cn

May 31, 2022 (HP151). Since 2008, iron-based superconductors (IBS) have attracted wide interest for both basic research and practical applications, due to their unique performance, such as a high superconducting transition temperature (T_c), a large critical current density (J_c) over 1 MA cm^{-2} in thin films, a very high upper critical field above 100 T and a low anisotropy. Numerous studies have been reported to improve the critical current density of this superconductor and to optimize the manufacturing process of the superconducting tape. For instance, the critical current density of short sample $Ba_{1-x}K_xFe_2As_2$ tapes can reach 1.5×10^5 A cm^{-2} at 10 T and 4.2 K, and still maintain 10^5 A cm^{-2} at 14 T and 4.2 K in a short sample [1], and first 100-m class IBS tapes were successfully prepared [2]. All these excellent properties of iron-based superconductors indicate its application prospects in high-field magnets.

High-performance superconducting joints will be the key point to employ IBS in nuclear magnetic resonance spectroscopy and magnetic resonance imaging. These applications need its magnet to generate a stable magnetic field during operation, which requires the decay rate of the magnetic field to be less than 0.1 ppm·h^{-1} [3]. The first iron-based superconducting joint was successfully prepared in 2018 by hot pressing method [4]. Subsequently, the critical current ratio of the superconducting joint was improved to 63% at 4.2 K and 10 T by prolonging the holding time and reducing the pressure during hot press [5].

Recently, a simple and effective method for joining IBS superconducting tapes based on the cold-pressing technique has been found [6]. In this work, the world's first persistent current operation of high-performance $Ba_{1-x}K_xFe_2As_2$ (Ba122) superconducting joints was reported. The results show that the joints fabricated under high pressure have fewer microcracks and pores, and hence better connectivity, leading to better superconducting properties than other joining techniques. The critical current of the joint increases monotonically with the increase of the applied pressure from 0.69 to 2.3 GPa, and then the critical current ratio are almost the same at 4.2 K and 10 T when the pressure further increases to 3.68 GPa. The best IBS joint sample shows a fairly high critical current ratio of 94.6% at 4.2 K and 10 T, which means that the IBS superconducting joints exhibit properties even closer to that of a single tape. On the other hand, a field-decay measurement was developed in order to accurately measure the joint resistance of

Ba-122 single closed-loop coil. The self-field at the Hall sensor generated by the closed-loop coil was simulated, and an ultra-low-resistance of 2.7×10^{-13} Ω in self-field at 4.2 K was achieved by the field decay method. All these indicates that IBS are quite competitive for the construction of high-field magnets needed for nuclear magnetic resonance spectroscopy, magnetic resonance imaging, and also particle accelerators or fusion reactors. More details can be found in reference [6].

Professor Congreve in University of Cambridge comments this work in *Superconductor Science and Technology*; he said: "This work is undoubtedly an important step forward in the of use of IBS in practical persistent mode applications. It will be interesting to see how this affects the development of wider practical applications of IBS in engineering applications and the materials competitiveness with respect to other superconducting materials." [7]

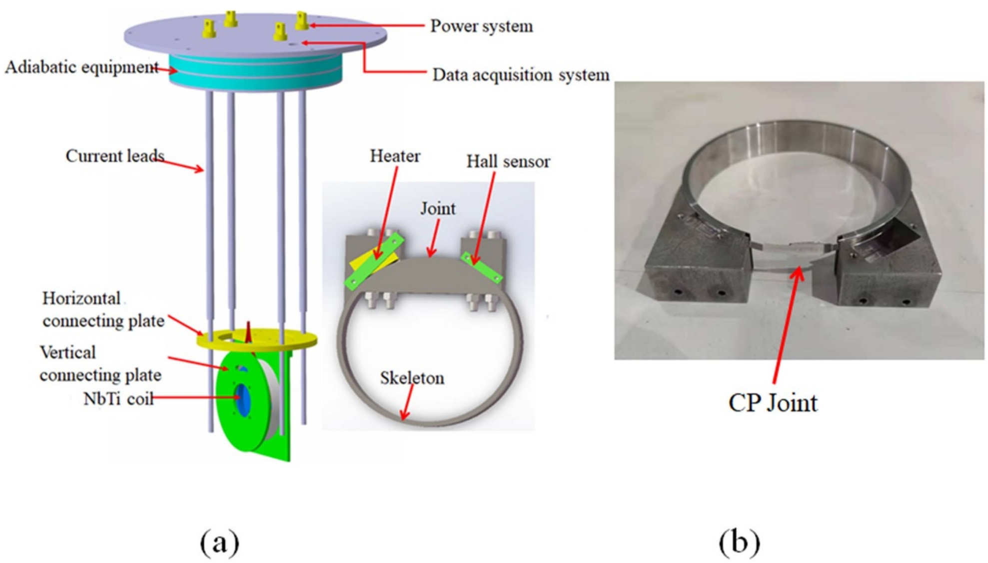

Figure1. (a) Field-decay measurement setup. (b) Ba-122 closed-loop coil [6]

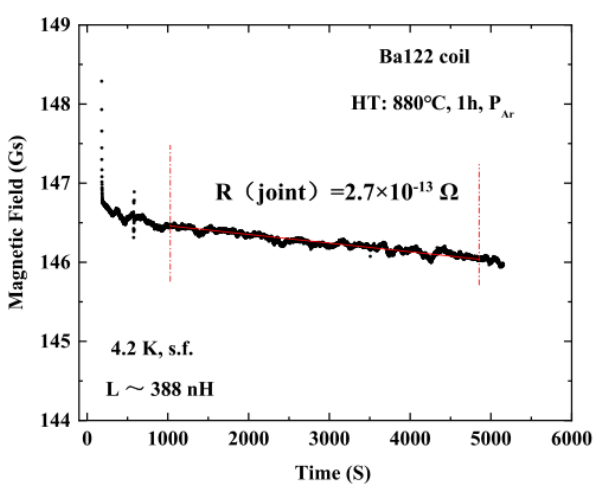

Figure 2. Time decay curve of the captured magnetic (y-axis field is the induced field in the closed-loop coil) [6]

References

[1] Huang H, Yao C, Dong C H, Zhang X P, Wang D L, Cheng Z, Li J Q, Awaji S, Wen H H and Ma Y W 2018 High transport current superconductivity in powder-in-tube $Ba_{0.6}K_{0.4}Fe_2As_2$ tapes at 27 T *Supercond. Sci. Technol.* **31** 015017

[2] Zhang X P, Oguro H, Yao C, Dong C H, Xu Z T, Wang D L, Awaji S, Watanabe K and Ma Y W 2017 Superconducting Properties of 100-m Class $Sr_{0.6}K_{0.4}Fe_2As_2$ Tape and Pancake Coils *IEEE Trans. Appl. Supercond.* **27** 7300705

[3] Patel D, Matsumoto A, Kumakura H, Moronaga T, Hara Y, Hara T, Maeda M, Hossain M S A, Yamauchi Y, Choi S and Kim J H 2021 Superconducting Joining Concept for Internal Magnesium Diffusion-Processed Magnesium Diboride Wires *ACS Appl. Mater. Interfaces* **13** 3349

[4] Zhu Y C, Wang D L, Zhu C D, Huang H, Xu Z T, Liu S F, Cheng Z and Ma Y W 2018 Development of superconducting joints between iron-based superconductor tapes *Supercond. Sci. Technol.* **31** 06lt02

[5] Zhu Y C, Wang D L, Huang H, Xu G X, Liu S F, Cheng Z and Ma Y W 2019 Enhanced transport critical current of iron-based superconducting joints *Supercond. Sci. Technol.* **32** 024002

[6] Zhu Y C, Wang D L, Wang Q Q, Zhang Z, Guo W W, Huang H, Ma H J, Liu F, Liu H J and Ma Y W 2022 High-performance $Ba_{1-x}K_xFe_2As_2$ superconducting joints for persistent current operation *Supercond. Sci. Technol.* **35** 03LT01

[7] Jasmin V J Congreve 2022 High-performance joints between iron-based superconductors: a key step towards applications *Supercond. Sci. Technol.* **35** 070501