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A novel method of flat YBCO rings development for shield-type superconducting fault current limiters fabrication

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ABSTRACT

The application of flat superconductor rings has been investigated in the structure of inductive shield-type high temperature superconducting fault current limiters, HT_c-SFCL. A laboratory scale inductive shield-type HT_c-SFCL has been designed and fabricated using flat superconductor rings. The fabrication process has been fully presented. YBCO powder has been used for the fabrication of superconductor rings. This fabrication process, being quite innovative, is introduced completely. The method of the trapped field measurement has been used for the critical current density measurement of the fabricated superconductor rings. The device with nominal current of 2 A was tested in a 30 V circuit. The SFCL successfully limited the fault currents of up to 10 times the nominal current to an approximately fixed value of 3 A. The voltage–current characteristic of the fabricated prototype has also been obtained and has shown compatibility with the fault current limitation results.

1. Introduction

Based on ability to carry transport current in the presence of high magnetic fields at liquid nitrogen, bulk $YBa_2Cu_3O_{6+x}$ (Y123 or YBCO, $0 < x < 1$) ceramic superconductor has significant potential for practical high field engineering applications. Melt-texture processing is known to be a promising way to fabricate high temperature bulk superconductors (like YBCO). There are some methods to fabricate YBCO samples by melt-texture method that details are elsewhere [1–5]. Because the brittle nature of ceramics makes it hard to machine them into required shapes as rings, shaping is an important aspect of these materials for applications. The shaping aspects of high temperature ceramic superconductors have been undergoing intensive research [6–8]. For making a flat ring of high temperature ceramics the usual method is to fabricate a pellet and drill the center of it [9,10]. In this paper the ring is fabricated directly by use of suitable cast and then it has been annealed by melt-texture method. Commercial high purity YBCO powder (99.99) has been used for superconductor ring fabrication. The critical current density of fabricated ring is also measured with the method of the trapped field measurement using a magnet device. The fabricated flat superconductor ring has been utilized in the structure of inductive shield-type SFCLs and its impact in the current limitation of SFCLs has been investigated.

The superconducting fault current limiter, SFCL, can be used to limit the short-circuit current level in electrical transmission and distribution networks and is one of the most promising devices for transmission and distribution of electrical energy due to low nominal losses, reliable operation, very short reaction times to fault currents and an automatic response feature without the requirement of an external trigger mechanism [11,12].

An inductive current limiter operates like a transformer that has a shorted superconducting secondary winding. The impedance of this current limiter under normal operating conditions is nearly zero, since the zero impedance of the secondary superconducting winding is reflected on the primary circuit. In the event of a fault, the secondary winding transits from superconducting state. Thus the secondary resistance will increase which will subsequently limit the fault current [13–16].

The secondary winding may be a high temperature superconductor (HTS) bulk cylinder whose function under normal condition is to shield the flux generated by the primary winding from entering the iron core of the current limiter. The primary winding is usually made from copper connected directly to an electric circuit. In the normal operation of the SFCL, according to the induced currents associated with the critical state model, no flux enters the core and the SFCL shows a low inductance. In the fault condition the ampere-turns balance of the transformer is destroyed and flux from the primary winding enters the iron core. The inductance and impedance of the primary winding rapidly increase limiting the fault current of the circuit [12,17]. Various designs have been proposed [11,17–23]. Nowadays, HTS bulks are broadly used in worldwide SFCL projects. References [24,25] discuss the use of HTS bulks in a large-scale SFCL and their advantages. Meanwhile, the application of SFCLs with bulk superconductor material is developing as a

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protection device in power systems and some devices are already installed as in [26]. Furthermore, taking into account the fabrication simplicity and the lower costs of HTS bulks relative to other alternatives, it seems to stay as an important choice for use in future SFCLs. Improvements in HTS properties, such as flux pinning and the ability to grow large grains, have greatly improved the economics of applications that use bulk HTS [27].

Using the fabricated flat superconductor rings, a prototype SFCL has been fabricated and tested in a circuit. Faults have been imposed and the experimental test results have been reported.

2. The structure of the SFCL

According to part 1, a two dimensional view of the SFCL structure – due to the existing axial symmetry – is shown in Fig. 1. The primary copper winding has been split into two windings and the superconductor flat ring is placed between these two winding parts.

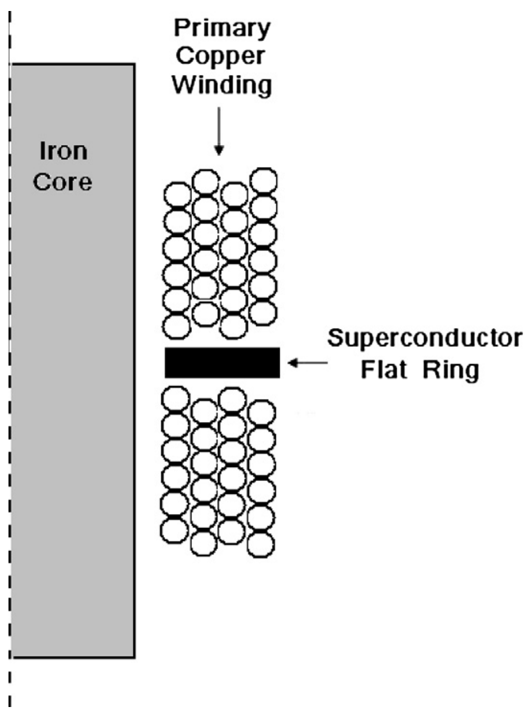

Fig. 1. The structure of the proposed SFCL.

3. Flat superconductor ring fabrication

3.1. Casting

A four piece cast is used for casting of the flat YBCO ring, as shown in Fig. 2. The YBCO powder is pulverized thoroughly and poured with acetone, for its better flow and to fill the cast in a better form. The amount of powder is determined from the bulk YBCO material density of approximately 5 g/cm^3 with the volume of the ring determined in the design process. With the dimensions of the ring as in Fig. 3, the amount of powder used was approximately 8 g.

As the preliminary fabrications showed some cracks on the upper surface of the ring, after press and removing the uppermost piece of cast, due to the pressures on this surface from bilateral forces, as shown in Fig. 2, the inner part of the cast, where the YBCO powder is poured, is impregnated with silicon rubber which harnesses the bilateral forces and a sound ring is obtained.

3.2. Pressing

The obtained flat ring through casting process is put under continuous pressure of 375 MPa which is chosen to be higher than known pressures in past bulk productions [28,29]. A sample flat ring, with given dimensions, is obtained after pressing it as shown in Fig. 3. For a ring having specific dimensions as in Fig. 3, a force of 20 Tons would be required. The cast has been put under this force for 24 h. As the silicon rubber penetrates the surfaces of the ring which have been in contact with it, these surfaces are scraped with thorn in order to get a high purity flat superconductor ring.

3.3. Annealing

The formed bulk flat ring should be put in the furnace for crystal formation. Two processes may be followed in annealing: the diffusion and the melt-texture. The temperature profiles of these methods defer both in terms of the temperature magnitude and in terms of the duration of the process. The critical current density of the superconductor rings obtained through these processes would be different. The temperature reaches a higher level in the melt-texture method rather than the Diffusion Method. So the formed polycrystals have larger sizes and the critical current density is higher. For this work, in the melt-texture process the ring was heated up to 1030 °C with a ramp of 10 °C/min without overshooting and was hold constant at this temperature for 70 min. Then the sample was cooled down quickly to 970 °C and was hold at this temperature for 24 h. At the end, the oxygenation was performed at the temperature range between 400 and 600 °C for 20 h.

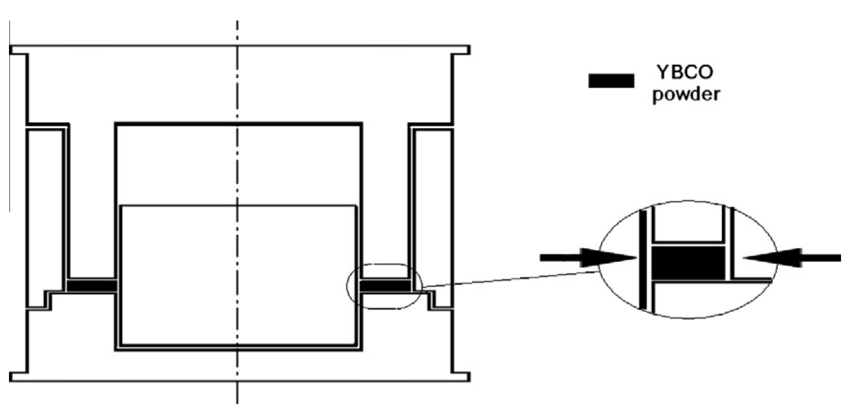

Fig. 2. The four piece cast for bulk ring production.