FABRICATION AND TEST OF SHORT HELICAL SOLENOID MODEL BASED ON YBCO TAPE*

M. Yu#, V. Lombardo, M.L. Lopes, D. Turrioni, A.V. Zlobin, Fermilab, IL 60510, U.S.A.
G. Flanagan, R.P. Johnson, Muons Inc., Batavia, IL 60510, U.S.A.

Abstract

A helical cooling channel (HCC) is a new technique proposed for six-dimensional (6D) cooling of muon beams. To achieve the optimal cooling rate, the high field section of HCC need to be developed, which suggests using High Temperature Superconductors (HTS). This paper updates the parameters of a YBCO based helical solenoid (HS) model, describes the fabrication of HS segments (double-pancake units) and the assembly of six-coil short HS model with two dummy cavity insertions. Three HS segments and the six-coil short model were tested. The results are presented and discussed.

INTRODUCTION

A HCC has been proposed for 6D cooling of muon beams [1]. It is based on a continuous absorber and RF cavities imbedded into superconducting magnets which superimpose solenoid, helical dipole and helical gradient field components. The HCC for muon collider is divided into several sections, each section with progressively stronger fields, smaller aperture and shorter helix to achieve the optimal muon cooling rate [2].

To study and demonstrate the HCC low-field section, two four-coil HS models based on NbTi Rutherford-type cable were designed, fabricated [3] and tested [4] at Fermilab. The HCC high-field section, due to its high operation conditions, requires using coils based on High Temperature Superconductors (HTS) [5]. Furthermore, the RF cavities inside the coil are required to operate at the temperatures above 30 K (assuming gaseous H_2 is used as the absorber), and there will be very little space to fit the thermal insulation and support structure in between the RF system and the magnets. The use of HTS can solve this problem by allowing the operation of both the magnets and RF system at the same temperature. Therefore, development of the design and fabrication technology of a high-field HS based on HTS material is critical for realizing a practical HCC. HTS coils based on the present practical HTS materials Bi-2212 wire and YBCO tape were studied and compared. YBCO tape was selected as the conductor for the model due to its better mechanical properties, compared with Bi-2212 wire [6]-[7]. Besides, the present YBCO tape, provided by Superpower, has better I_c performance than Bi-2212 wire at both 4.2 K and 33 K.

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#miaoyu@fnal.gov

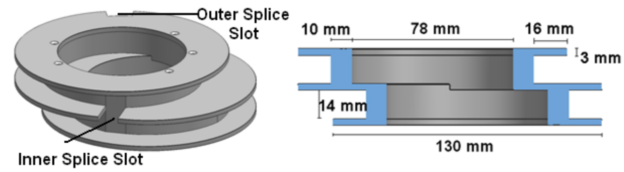


Figure 1: A double-pancake unit.

MODEL PARAMETERS

Figure 1 shows the assembled mechanical structure of a double-pancake unit with dimensions. Such design allows assembling all the units into a longer helical solenoid by replacing one side flange with a connecting flange which accommodates the splices between units. Moreover, the modular structure of HS also allows providing a gap between two units to insert cavities and absorber feed throughs [8].

The target design parameters for the high field section of HCC were listed in [9]. To reach the required field components, a continuous HS without any insertions should consist of at least 24 double-pancake units. An HS with a cavity system insertion between two double-pancake units requires some adjustment to the design parameters to meet the field requirement, but the mechanical concept of HS with the cavity is the same.

Conceptual design studies were performed using individual double-pancake units; 3- double-pancake units combined into a continuous assembly; and double-pancake units with G10 dummy cavities insertions in between the units. SCS12050 Superpower YBCO tape with a nominal I_c(0T,77K) = 330 A was used as the conductor for the studies as well as for the fabricated double pancake coils. Table 1 shows the parameters of the models predicted performance at 4.2 K.

Table 1: HS Short Models Parameters

Parameter	Unit	Number of Double-pancake Units (Number of Cavity Insertion)		
		1 (0)	3 (0)	3 (2)
Coil ID	m	0.10	0.10	0.10
Coil OD	m	0.116	0.116	0.116
Number of turns/coil		58	58	58
Predicted I_{quench}	kA	1.424	1.348	1.375
Maximum Coil B ⊥ Field	T	3.4	3.7	3.6
Inductance	mH	1.6	7.4	9.1
Stored energy	kJ	1.6	6.7	8.6

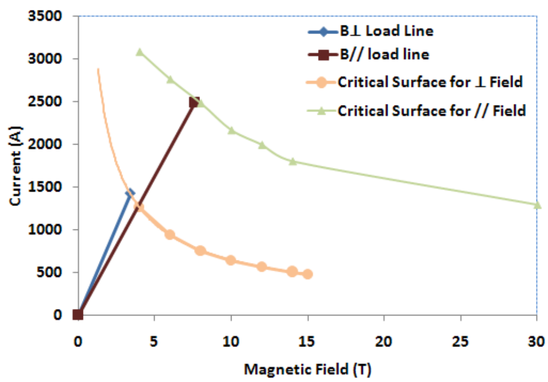


Figure 2: Critical current with the load line.

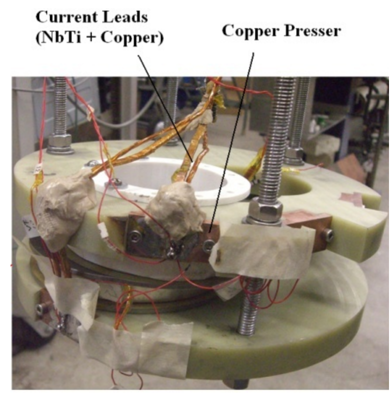


Figure 4: One unit assembly for test.

Figure 2 shows the critical current of the SCS12050 Superpower YBCO tape at 4.2 K with the double-pancake load line. The critical currents were measured and then fit to a polynomial curve. As shown, the predicted I_{quench} or the short sample limit (SSL) of each model is limited by the maximum perpendicular field to the coil due to the angular dependence of the YBCO tape [10].

COIL FABRICATION AND TEST

The double-pancake coils were wound continuously, described in [9]. The two spools of YBCO tape were soldered together by a piece of 12 mm YBCO tape in a way to fit inside the inner splice slot shown in Figure 1. 0.05 mm Kapton tape was co-wound with the coil for turn to turn insulation. 0.5 mm G10 ring sheet plus 0.05 mm Kapton tape were glued to the side flange. Ten-layer 0.05 mm Kapton tape was wound around the structure ring as the ground insulation. After coil winding, two outer splices are soldered to the coils. On top of the coil, ten-layer 0.05 mm Kapton tape was wound as the ground insulation, and fifteen-layer 0.1mm SS shim was wound as the bandage. The coil side view is shown in Figure 3.

Three double-pancake units were fabricated and tested. Figure 4 shows one unit with the test interface. Outer coil connections were made using a copper presser which was tightly pressed to the outer splice with a piece of indium inserted in between to increase the contact surface. NbTi wires and copper straps were soldered to the copper presser and the concentric current lead for both 77 K and 4.2 K test.

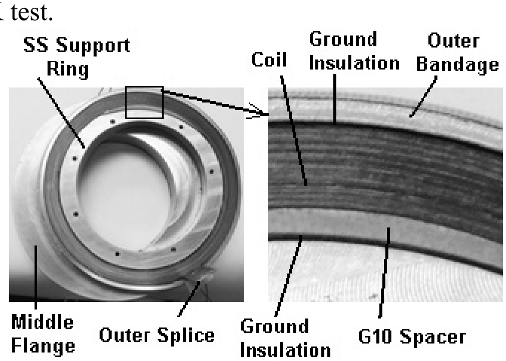
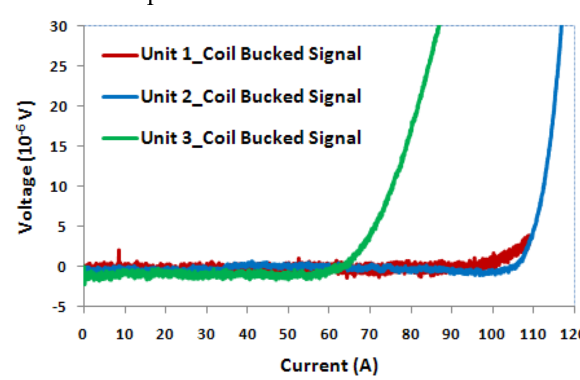
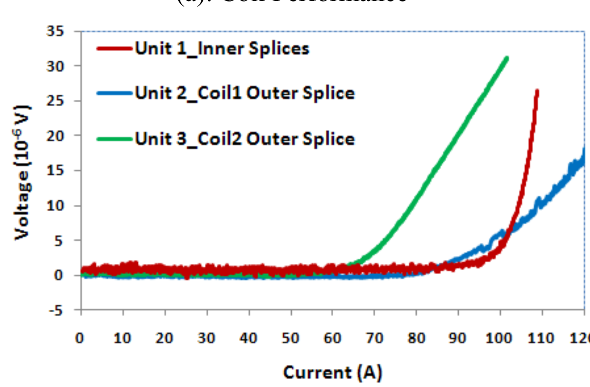


Figure 3: Side view of one coil in a double-pancake unit.

All the three units were tested at 77 K, with the SSL ~103 A. The voltage vs. current measurements of the coils and splices are shown in Figure 5. Note the voltage signals of two coils in each unit are bucked for noise reduction. Unit 1 was wound and rewound several times, in the process adding voltage taps to localize the quench origin. Finally it was determined that the quenches originated in the splice region. Once repaired HS unit 1 reached ~90% SSL [11]. Unit 2 reached ~80% SSL, and unit 3 reached ~60% SSL. In unit 3, quenches are observed in both double pancake coils as well as in one of the outer slices. Coil 1 quenched at ~80 A, and coil 2 quenched at ~60 A, the same as the coil 2 outer splice. Further tests are needed to determine the quench location in unit3. In general, the splice performance needs to be studied and improved.



(a): Coil Performance



(b): Splice Performance

Figure 5: Test results of three HS units at 77 K.

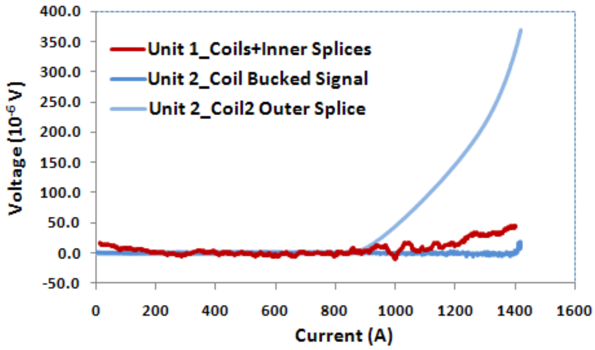


Figure 6: Test results of unit 1 and 2 at 4.2 K.

Unit 1 and unit 2 were tested at 4.2 K, and the quench detection and protection were described in [11]. Figure 6 shows the performance of the two units. For unit 1 the signal of both coils plus inner splices was monitored due to the lost of voltage taps near the inner splices. Unit 1 reached ~80% SSL, with degradation occurring in the inner splices. Unit 2 reached ~60% SSL with degradation in one of the outer splices. The results indicate that the degradation percentage (percentage decreases from SSL) doubled at 4.2 K, compared with the same degradation at 77 K.

HS MODEL ASSEMBLY AND TEST

To study the effect of having an RF cavity inserted inside the HS, three HS units and two dummy cavities were assembled, shown in Figure 7. Unit 3 was placed in the middle of the model to avoid the higher fringe field (perpendicular to the coil) going through this unit that has larger degradation, this way the performance will be the best. All units will be electrically connected through the YBCO splices, while for this test pancake to pancake connections were made mechanically using copper or aluminium pressers.

Since all three units were tested separately at 77 K with the current up to 100 A, and the performance of each is already known, the short demo model was mounted and tested at 77 K, with SSL ~98 A. The test results are shown in Figure 7, with bucked signals. Unit 3 quenched at ~70 A, 71% SSL. The large spikes in the signal are likely due to loose connection of the splices between two units.

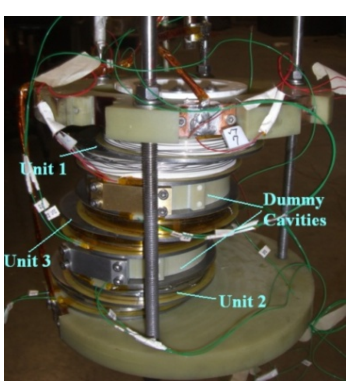


Figure 7: Short HS model assembly with dummy cavities.

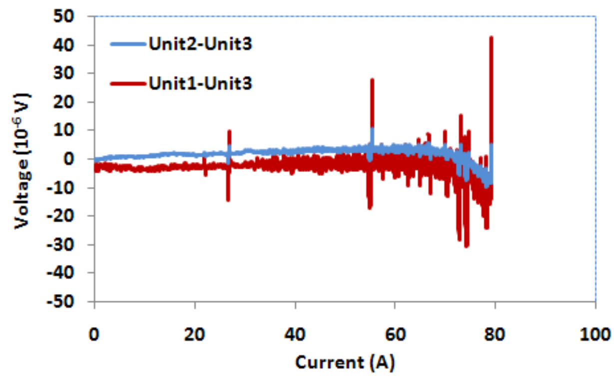


Figure 9: HS short model test results at 77 K.

CONCLUSION

The HS double-pancake unit was designed, and three units were fabricated and tested successfully. At 77 K, the best performance reached 90% SSL, and at 4.2 K 80% SSL. YBCO tape can be reused after the coil fabrication. Despite 10 unwinding-rewinding in one double pancake, no conductor degradation was observed. The HS short model with G10 dummy cavities was assembled and tested at 77 K.

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