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HTS Quadrupole Magnet for the Persistent Current Mode Operation

Vladimir Kashikhin, Daniele Turrioni

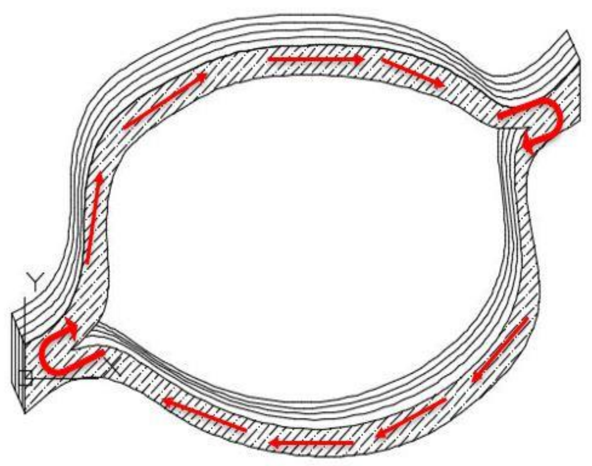
Abstract

The new high temperature superconducting (HTS) quadrupole magnet with circular coils was designed and built at Fermilab. There were investigated also several HTS coils at the liquid nitrogen temperature. The main goal of this activity is to investigate coils, and the magnet operation in a persistent current mode to reduce accelerator magnets capital and operational expenses. For that were used HTS short-circuited coils. In the paper discussed HTS coils and magnet design, fabrication, and tests. There were measured magnetic field in the magnet aperture and the field decay when the magnet operates in the "frozen flux" mode. The test results are compared with simulations and confirmed advantages of the proposed approach.

Introduction

This paper describes initiated at Fermilab activity related to the design, fabrication, and test HTS coils and quadrupole magnets. In previous papers [1] – [2] were presented novel configurations of multipole iron dominated magnets with circular superconducting coils. This magnet configuration is most suitable for fabrication of round coils wound from HTS tape type superconductor which is sensitive to sharp bends and deformations. At the same time there is a substantial interest to design magnet systems capable to operate in a persistent current mode like MRI NbTi based solenoids. We explore another novel technology where the HTS coil assembled from parallel superconducting loops. In this case the magnet system consists of from the primary coil used as a magnetic field source and secondary one where induced current circulates.

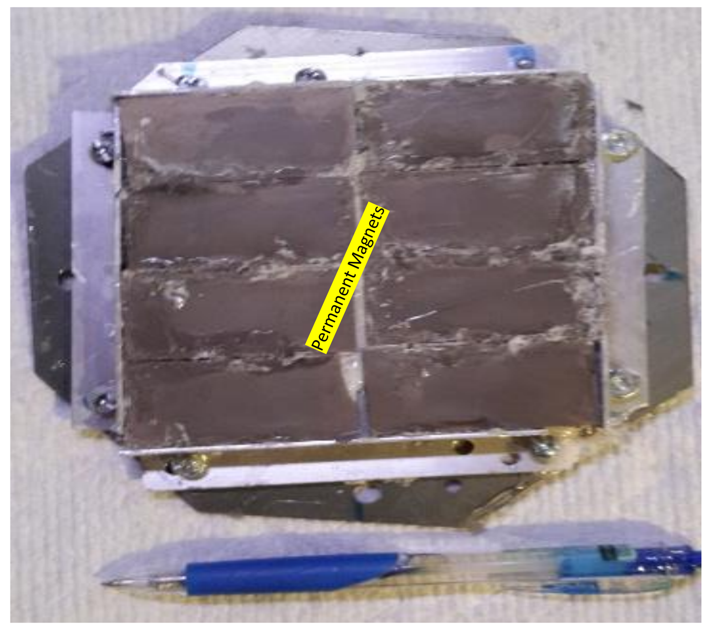
Closed Loops HTS Coils

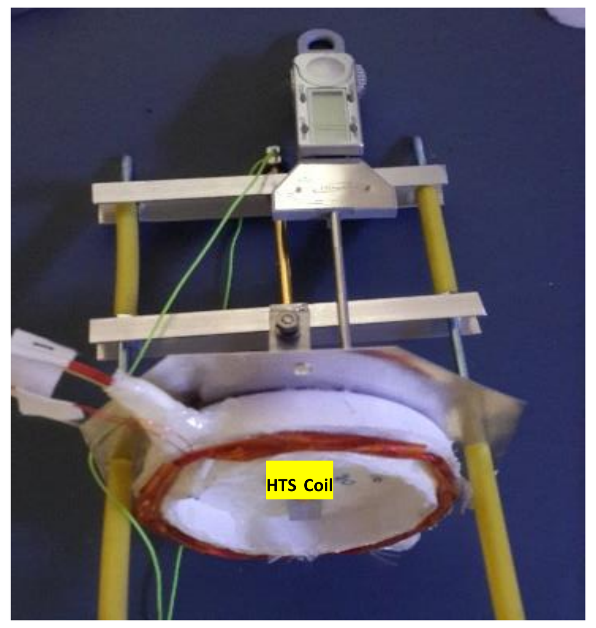


Multilayer HTS Coils

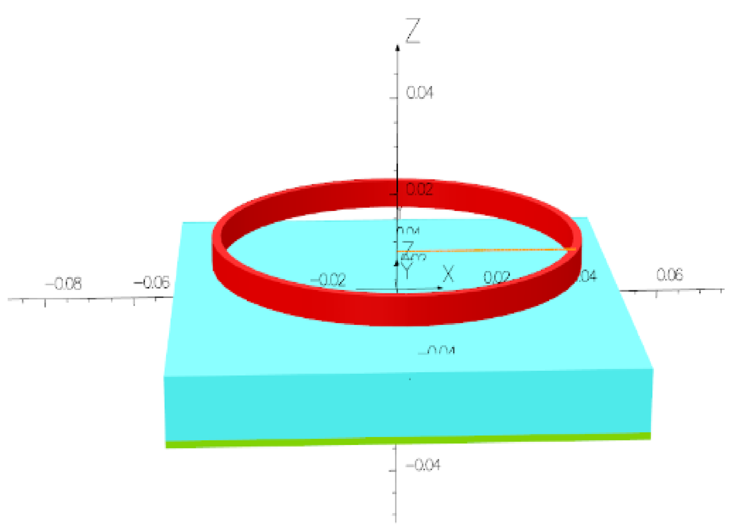
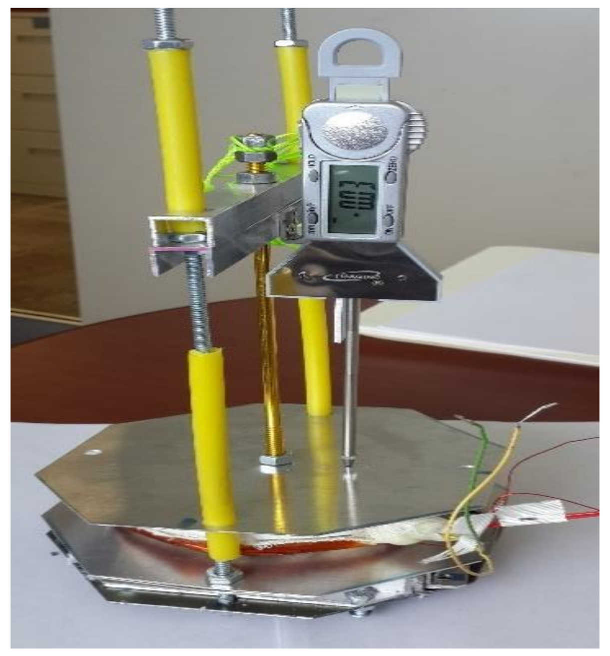
The main idea of the proposed HTS coils is to use a stack of HTS tapes and cut them in a longitudinal direction without cutting at ends. Coil ends should have enough length to transport the circulating in the loop current. After the cut the stack of loops formed in a round or other form configuration as shown in the above figure.

Coils Cold Tests

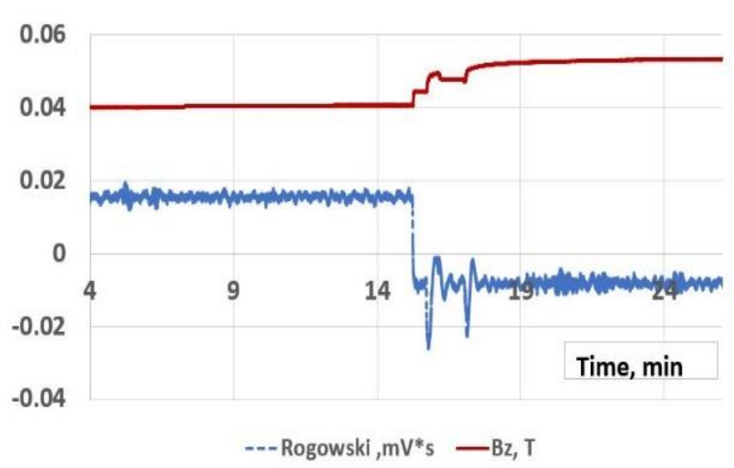


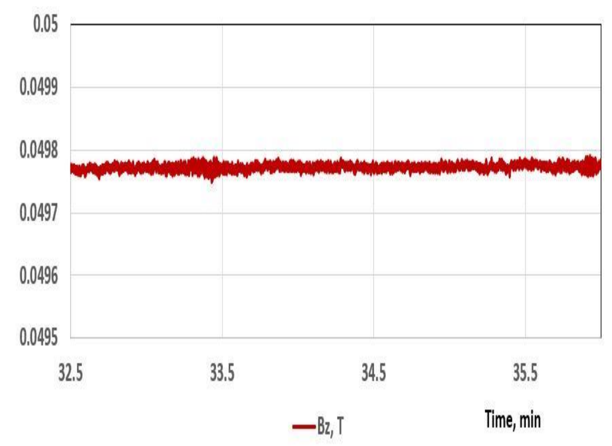


For the initial coil tests in LN2 was used the permanent magnet setup to generate the primary magnetic field in the vicinity of HTS coil to induce the current in the coil.

The test setup was placed in the can and filled with a liquid nitrogen. The coil was in the upper most vertical position. After several minutes of assembly cooling, the coil was released and dropped to the self-supporting (levitated) position.



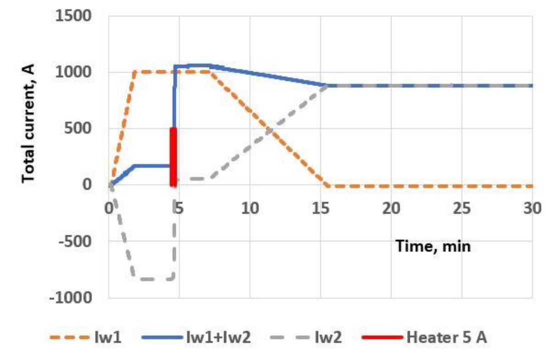


When loaded with an extra weight 1.2 kg and 2.4 kg the induced current increases to 655 A and 1017 A until the gap between permanent magnet and coil closes. In this case in coil circulates the maximum possible current defined by the strength of permanent magnets and a superconductor critical current.

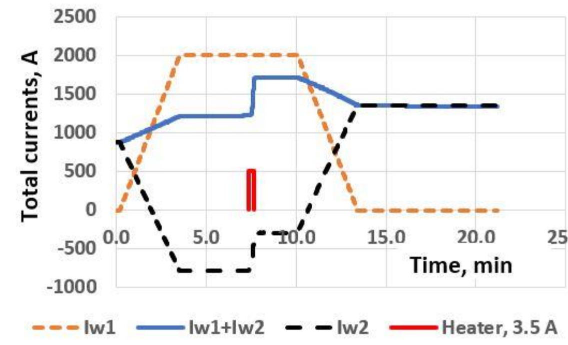
HTS Quadrupole

Quadrupole magnet with HTS primary and secondary coils

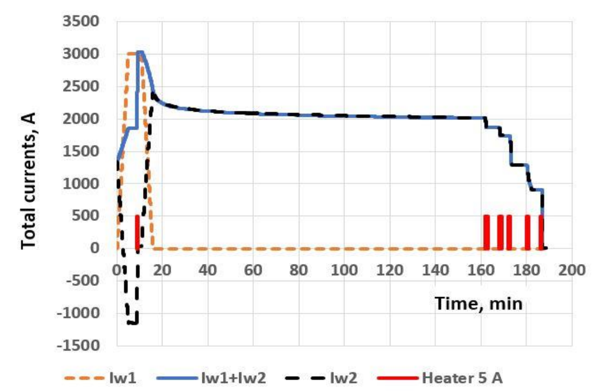
For the quadrupole magnet was used the iron yoke and primary HTS coil from previously tested magnets [2]. In the space between the yoke and coil was mounted the secondary HTS coil assembled from 50 HTS closed loops. Around coil was wound a nichrome heater wire and Rogowski coil to measure the current. The heater was used to clear initially induced in the secondary currents. Then the primary was ramped down to induce the continuous current in the secondary.



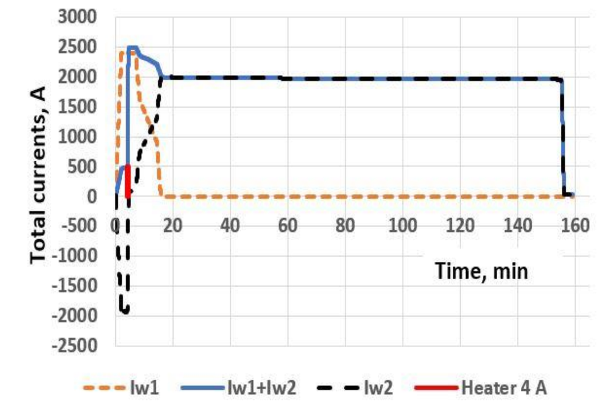
HTS magnet induced 833 A current.



HTS magnet induced 1344 A current.



HTS magnet induced 2283 A current.



HTS magnet induced 1900 A current.

Summary

Several HTS coils having closed loops configuration were successfully tested with the permanent magnet and the quadrupole yoke setup. During tests no magnet quenches were observed. There was successfully demonstrated HTS coils and the quadrupole magnet operation in a persistent current mode without an external power source.

[1] V.S. Kashikhin, "A Novel Design of Iron Dominated Superconducting Multipole Magnets with Circular Coils", *IEEE Trans. on Applied Superconductivity*, 2010, Vol. 20, Issue 3, pp. 196-199.

[2] V.S. Kashikhin, J. DiMarco, A. Makarov, Z. Mendelson, S. Rabbani, S. Solovyov, D. Turrioni, "High Temperature Superconducting Quadrupole Magnets with Circular Coils", *IEEE Trans. on Applied Superconductivity*, 2019, Vol. 29, Issue 5, 4002404.