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Development of Physics Teaching Materials Using a Simple Superconducting Coaster

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Abstract. Superconductivity is a renowned phenomenon, wherein a small neodymium magnet hovers on a superconductor. However, a desk-size superconducting coaster, which floats and runs on a magnet, is rarely used in classroom exhibitions. Moreover, students' production and demonstration of this phenomenon has been relatively difficult. Consequently, a simple interactive experimental system and teaching materials associated with methods of controlling the coaster's speed using a multiple-coil configuration were proposed by the National Institute of Technology, Ariake College. This experiment makes it possible to deepen students' understanding of electromagnetism and superconductivity through direct experience while also exposing them to programming methods using "Arduino." This paper describes the construction method of the desk-sized superconducting coaster and the analytical methods used to evaluate it.

1. Introduction

While the phenomenon of a magnet moving along the surface of a superconductor is widely taught, practical experiments that use an actual "superconducting coaster" ^[1] are more rare. Consequently, superconductivity equipment, including a resin block and a duralumin board, were manufactured by a small team at the National Institute of Technology, Ariake College ^[2]. The experiment also required the fabrication of a superconductor by sintering pressed powder. This simple superconducting coaster offers a unique opportunity for students in the field of the electrical engineering to work with superconductors in the classroom and laboratory setting.

2. Construction of the Superconducting Coaster

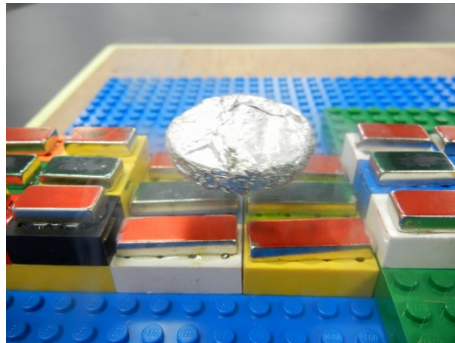
A superconducting coaster comprises a magnetic "track" and a superconductor.

2.1 Construction of the Magnetic Track

It is possible to construct a superconducting coaster by lining up neodymium magnets. A track using a resin block is presented in Figure 1 and has been developed to determine the magnet spacing ^[2]. Prominent parts in a resin block were cut and the neodymium magnets were attached using glue as a bonding agent. This configuration makes it possible to consider the optimum arrangement of the magnets according to the size of the superconductor, without having to worry about the attraction and repulsive forces of the magnets. The resin course is scalable, which also makes the experiment's size flexible. However, attention must be given to block as it moves to avoid accidents during exhibition. A



course with a magnet fixed on a duralumin board was developed, and the desk-size track was found to be the most suitable size for exhibition (see Figures 1 and 2). A system for measuring the magnetic field was also assembled and the magnetic field was measured, as shown in Figure 3.

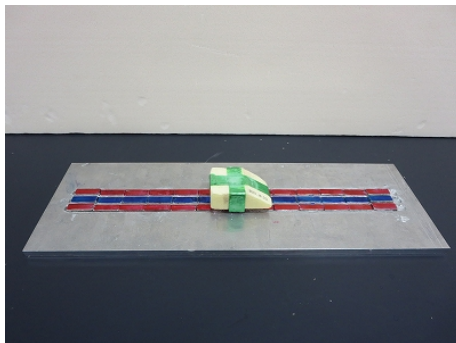


(a) Magnetic course and superconductor



(b) Exhibition of superconducting coaster

Figure 1. Superconducting coaster with magnetic course

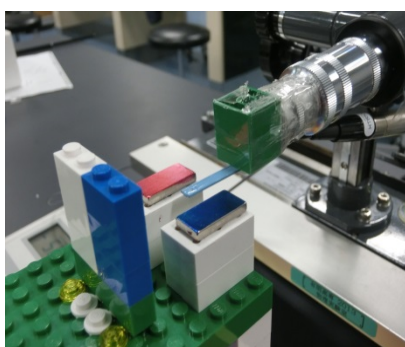


(a) Superconductor and magnetic course

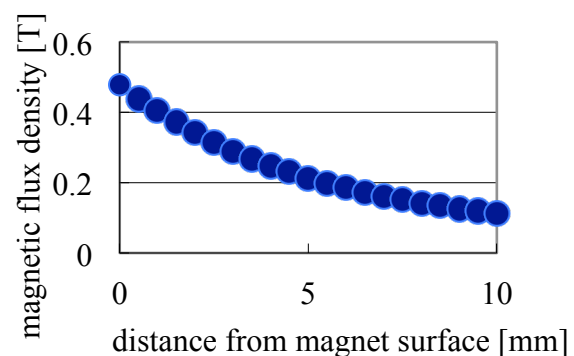


(b) Exhibition with superconducting coaster

Figure 2. Configuration and exhibition of superconducting coaster



(a) Measurement system with one or two magnets



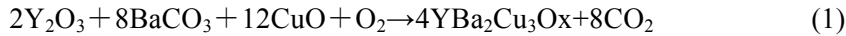
(b) Measurement with one magnet

Figure 3. Measurement of magnetic field

2.2 Making the Superconductor

A simple metallic mold was designed and fabricated to make it possible to produce a basic Yttrium Barium Copper Oxide (YBCO) superconductor^[3]. A hole was made in a SUS304 pillar by a turnery and processed to create the metallic mold designed to pressurize a superconducting pellet with a 3 cm diameter. A metallic mold was designed to handle the pressure generated in the production of the

superconducting pellet, as shown in Figure 4(a). Next, the relative amounts of the three kinds of raw material, Y_2O_3 , $BaCO_2$ and CuO were calculated and weighed using the mole ratio of Y: Ba: Cu of 1:2:3 as shown in Equation (1).



After mixing the raw materials together for 90 minutes, as shown in Figure 4(b) and pressurizing the resulting mixture with 20MPa of force for 10 minutes in the metallic mold, as shown in Figure 4(c), the pressed pellet was pre-baked for 2 hours at $900^\circ C$, then baked for 18 hours at $930^\circ C$. Thereafter, the finished YBCO pellet was cooled to room temperature, and the specific quality of the superconductor YBCO was evaluated. The magnet rose on the YBCO successfully, as shown in Figure 5(a), and the critical temperature was measured using the four-terminal method, which confirmed that impedance fell to zero at 89K, as shown in Figure 5(b). When the surface of the YBCO was analyzed using a Scanning Electron Microscope, the elemental analysis mole ratio becomes about Y: Ba: Cu equals 1:2:3 in the YBCO was confirmed.

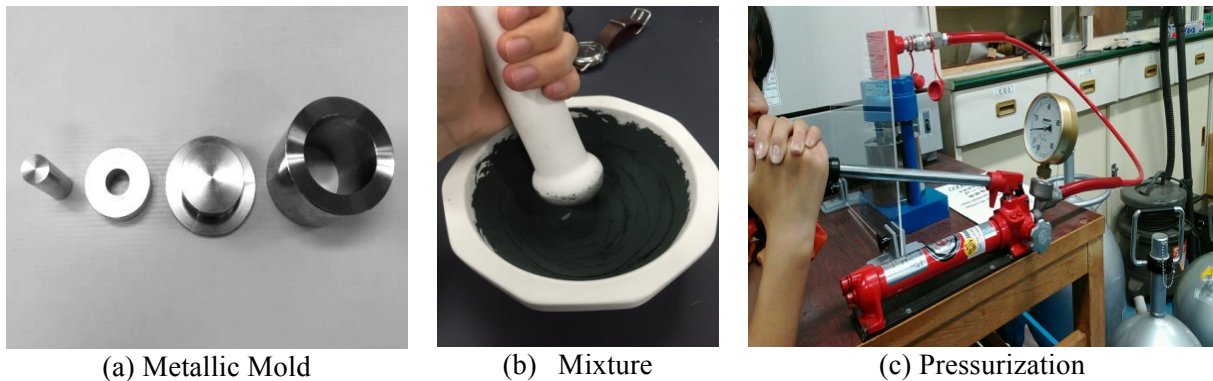


Figure 4. Fabrication of Superconductor

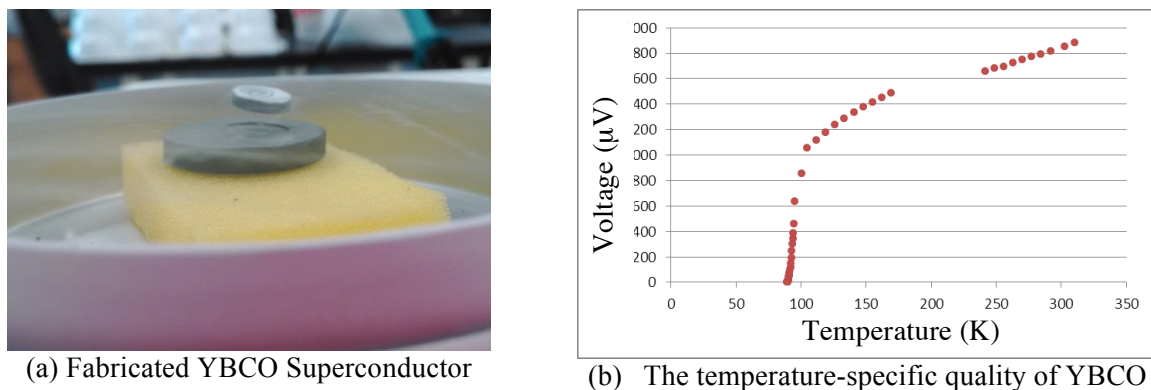


Figure 5. Measurement of the magnetic field

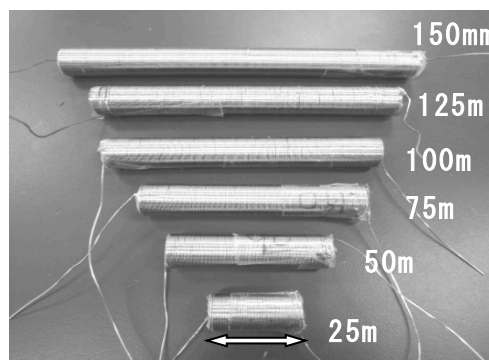
3. Summary and Future Tasks

We succeeded in manufacturing a superconductor with a magnetic track to create a simple superconductivity coaster system, and students involved in this project acquired knowledge of electrical engineering and superconductivity. We intend to focus our future research efforts on making a coil-type track and a speed control system. We are planning to spread the coil, which becomes an electromagnet, not a permanent magnet, over a rail of a coaster and control the electric current which flows to the respective coils using an “Arduino” microcomputer.

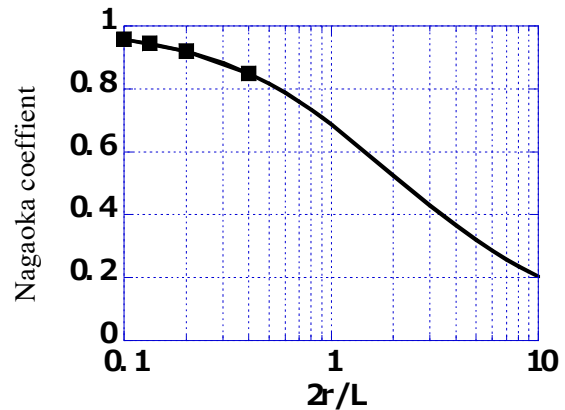
As a result of this experiment, we found that making an electromagnet with strength equal to a neodymium magnet was not easy. The well-known “Nagaoka coefficient,” which is used in the evaluation of inductance in a the length solenoid, as shown in Equation (2), helps to explain this.

$$K_N = \frac{4}{3\pi\sqrt{1-k^2}} \left[\frac{1-k^2}{k^2} K(k) - \frac{1-2k^2}{k^2} E(k) - k \right] \quad (2)$$

In Equation (2), K_N is the Nagaoka coefficient, k is variable for $\frac{l}{2r} = \frac{\sqrt{1-k^2}}{k}$, l is length of a coil, r is radius of a coil, and $K(k)$ and $E(k)$ are first-class complete elliptic integral about k and second-class complete elliptic integral. In Figure 6, a calculated value and measurement results are shown as an easy preceding task^[4]. When the coil is thick and short, it will be a circular coil, and when it is thin and long, it will be a solenoid. It will be necessary to make a stronger electromagnetic coil^[5] to construct a drive operation system for a superconducting coaster using an Arduino microcomputer.



(a) Test coils



(b) Nagaoka coefficient

Figure 6. Test coils and the Nagaoka coefficient

4 Acknowledgments

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