Northern Virginia Community College

SPS Undergraduate Research Award Final Report

Applications of the Superconducting Meissner Effect

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Introduction to Projects

We sought to develop two simple machines utilizing superconductors in order to understand the magnetic behavior of high temperature superconductors and provide a captivating demonstration of physics to the student body of NVCC. To that end we endeavored to understand the behavior of a superconducting flywheel and a Meissner pendulum.

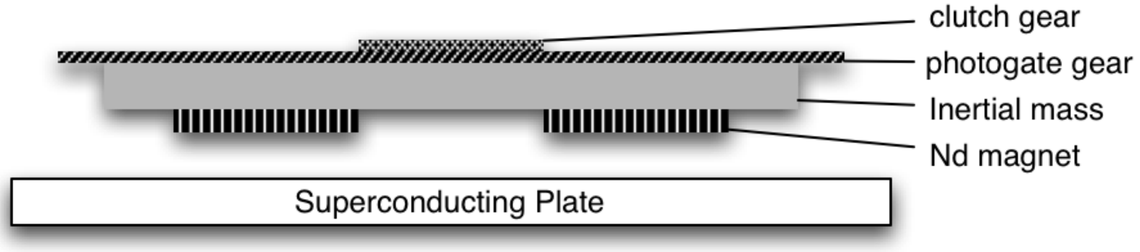
Superconducting Flywheel: Introduction

High-temperature superconductors (HTSC) have made it possible to demonstrate superconductivity at liquid nitrogen temperatures (77 K). In particular, samples of melt-processed $Y_1Ba_2Cu_3O_x$ provide a cost-effective and powerful demonstrator of superdiamagnetism. In our flywheel project, we sought to examine and demonstrate the behavior of these Type-II superconductors. With our apparatus, we are able to examine superdiamagnetism, the Meissner effect, and flux pinning. However, successful operation of the machine at high velocity depends on a number of technical details we were not able to overcome in our laboratory, and are outlined below.

There are several significant benefits to using superconducting magnetic levitation in a bearing system over mechanical bearing systems. Magnetic suspension provides a cushioning separation between mechanical components which protects the machine from catastrophic failure due to sheering or other direct-contact problems. Superconducting magnetic levitation is particularly interesting because it is a state of matter, and therefore takes energy to disable, which should in theory be possible to withhold. That is, superconducting magnetic levitation should be sustainable without the continuous input of great stores of energy and electronic tweaking, unlike current electromagnetic suspension technology. However, the foremost draw of magnetic suspension is the apparent lack of friction. This attribute is highly desirable in energy-storage situations, as friction constitutes an energy leach and a treat to system stability. Friction is the recipient of almost the entire net power output of any machine, and this is especially apparent in transportation. We examined the behavior a superconducting and mechanical bearing system to understand rotational friction as a function of velocity.

Superconducting Flywheel: Setup

The flywheel was constructed with a neodymium ring magnet (r1=50.8 mm, r2=25.4 mm, h= 6.4 mm), a variable inertial mass (one of several solid aluminum disks), a photogate flag gear, and a "clutch" gear used to accelerate the wheel and disengage during measurement. Below the flywheel is a plate of hexagonal $Y_1Ba_2Cu_3O_x$ superconductors in a pool of liquid nitrogen (LN_2).

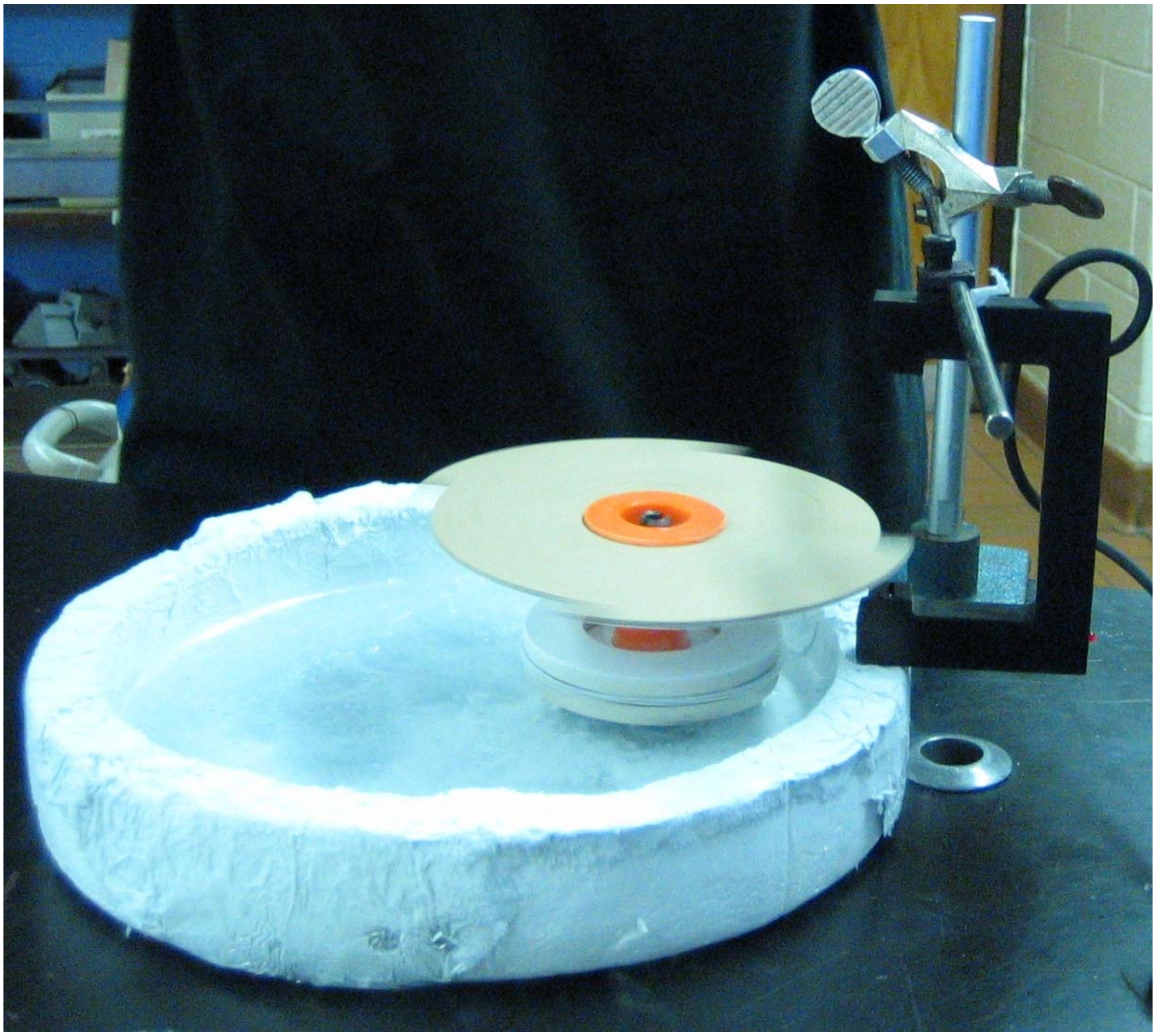


When the YBaCuO superconductors are cooled below their critical temperature ($T_C \approx 92$ K) they expel the magnetic field of the permanent neodymium ring magnet and produce a repulsion force, levitating the plate. This setup is stable due to an artifact of Type-II superconductors called *flux pinning*. Ordinarily in the superconducting state, the Meissner effect expels all magnetic fields from the interior of any material in the superconducting state. However, due to defects in the crystalline structure of melt-processed Type-II superconductors, magnetic flux lines become pinned inside the material, rather than being entirely expelled. As a result, the flywheel itself becomes "pinned" to the plate, resisting movement relative to the superconductors. However, because of the rotational symmetry of the magnetic field of the ring magnet, the flywheel is free to rotate without inhibition from this effect.

Superconducting Flywheel: Operation

Achieving rotational stability without machining parts is fairly difficult. The conceptual components remain the same, but the actual construction had to accomodate our equipment in the lab. For instance, the photogate, combined with the lip of the liquid nitrogen vessel required more clearance for the photogate gear. We use classroom software designed to measure linear velocity when an infrared beam is interrupted by a flag of a given length. We used this software for velocity data aquisition, and transformed the data.

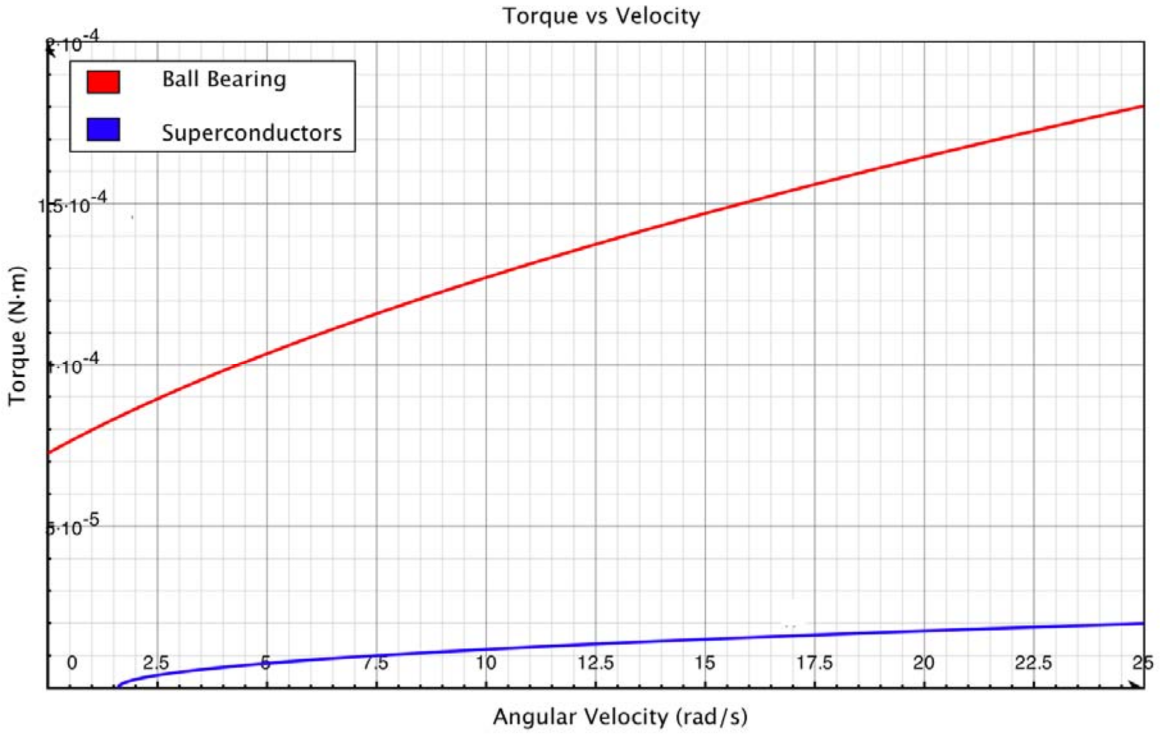
Unfortunately we learned that as the flywheel spun at higher speeds it had a tendency to drift.



We analyzed the data for the rate of deceleration as a function of velocity.

Superconducting Flywheel: Analysis

Using a quadratic fit to the data we recorded, we were able to derive an empirical model for the behavior of the rotational friction acting on the flywheel. However, though this was the nearest fit, it was only in the near case of 1.0 rad/s < ω < 30 rad/s. This was sufficient for our assumptions.



From our data we conclude that, not only is the friction of this system substantially less than that of our mechanical system, but more importantly that the rate at which friction increases with velocity is significantly lower than in the mechanical system.

Superconducting Flywheel: Summary

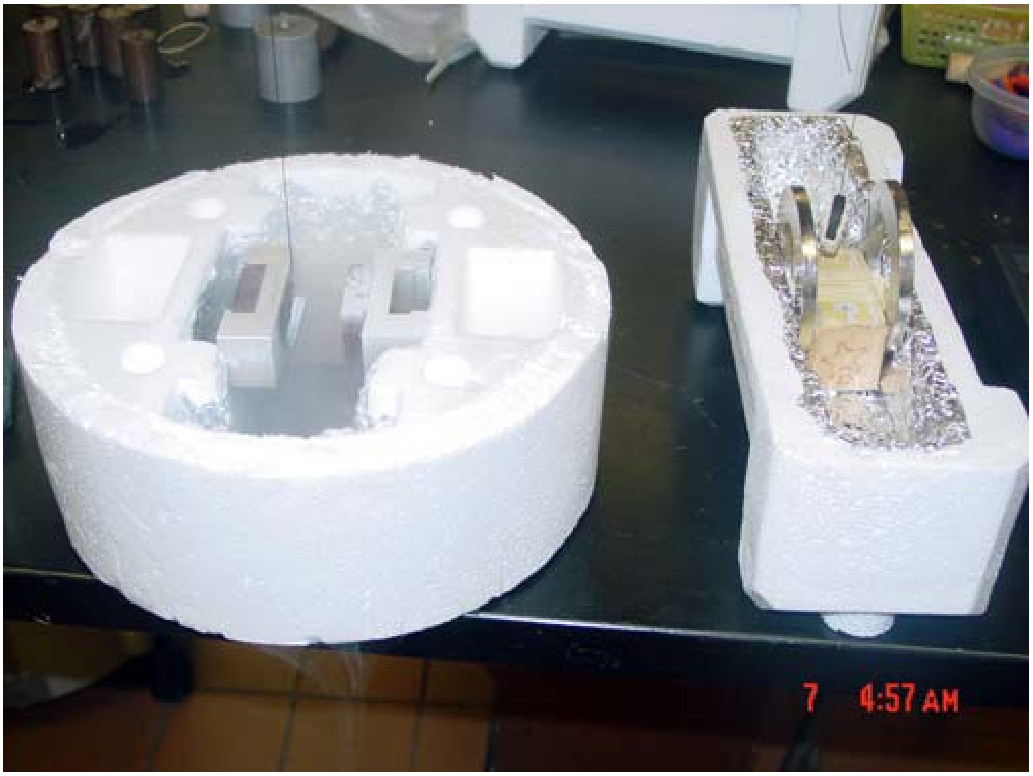
There is an apparent force involved in flux pinning. We are interested in empirically measuring and modeling this force, but have not yet constructed a method to successfully and reliably measure it. The factors which still obstruct us are the volatility of liquid nitrogen, control of the temperature of the superconductors, and the dozen tiny metal problems involved in measuring a force in the presence of strong magnetic fields. We plan to write a follow-up report once we've solved these problems without a Ruth Goldberg machine.

Meissner Pendulum

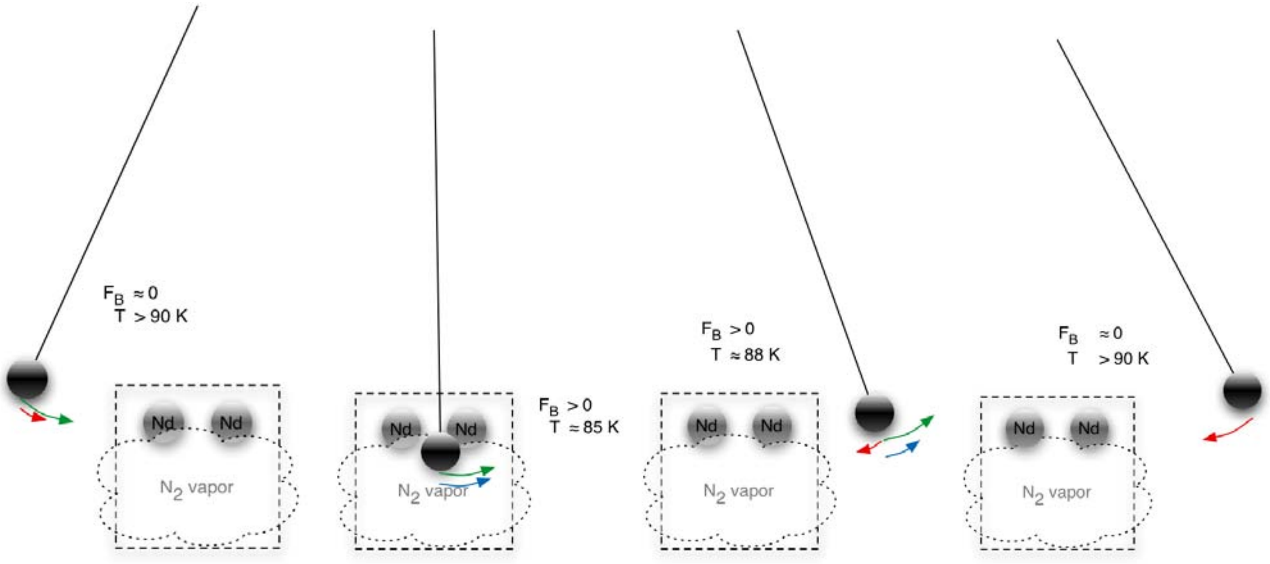
Our interest in this experiment is based on our prior membership's creation of a Meissner Heat Engine. This is a simple machine, a wheel, which rotates spontaneously at a constant velocity. HTSCs are positioned equidistantly along the circumference of the wheel. The lower edge of the wheel is immersed in a strong magnetic field and a vapor below the critical temperature of the superconductors. As the wheel rotates, the superconductors switch from insulators to superconductors at the right moment, expelling the magnetic field and receiving a kick. By the time the superconductor returns to the magnetic field it has been heated beyond its critical temperature by the environment.

Inspired by this, and a paper (Hegman, 1997), we sought to create a pendulum based on the Meissner principle. To date, we have been unable to recreate the Hegmen pendulum, nor our own. We think the source of our problem is the melt-processed superconductors which were ideal for the flywheel. We are currently seeking a means to quantify the culprit, the flux pinning effect.

Meissner Pendulum: Experimental Setups



In this setup, the HTSC served as the pendulum bob, and a magnetic field was created by using a Nd yoke to create a strong magnetic field. This was submerged in liquid nitrogen to create a environment of variable temperatures to allow the bob to cool below its critical temperature while in the yoke, and heat above it when at the top of its swing, as illustrated.



The superconductor achieves harmonic motion by entering the magnetic field, reaching its threshhold temperature while inside the field, and be repulsed out of the magnetic field until the HTSC once again exceeds threshhold temperature and descends once again to the magnetic field and cold environment.

Unfortunately,our setup did not produce an oscillating pendulum as we had anticipated. Our theoretical model was based on the assumption that the repulsive forces within the threshhold temperature environment would provide momentum to our HTSC bob to cross the other side of the Nd yoke. However, this did not occur; instead, the pendulum, upon entering the base in liquid nitrogen, began to experience flux pinning strong enough to cancel the momentum the repulsive forces provided. As a result, the pendulum bob entered the cold environment, was repulsed before the HTSC could cross the yoke, and was pinned just outside of the immediate area of the magnets.

The Hegmen pendulum (Hegmen, 1997) is described using a prism-shaped HTSC suspended from a piece of cotton string (l = 30 cm). Placed in a basin partly filled with LN2 is a riser, to set a cylindrical magnet above the level of the LN2. A piece of excelsior tissue allows the LN2 to rise above the level of pooled LN2 and come into contact with the freely hanging pendulum. The pendulum is cooled below its critical temperature and expels the field from the pole of the magnet and repels in a half-swing. As the pendulum is heated by the ambient environment, it returns to its insulator state. As described in the paper, it does this slowly as the sample is not of a uniform temperature, and oscillates between vertical and full-swing at a near constant speed.

We were not able to duplicate this experiment with our YBaCuO samples. Our samples are hexagons instead of prisms. Although geometry may play a factor, the real issue was the flux pinning phenomena. Our pendulum was never able to swing far enough from the magnet to be heated by the ambient environment, and was quite firmly fixed a short distance from the magnet's pole. We attempted this with another sample that was not melt-processed, but this sample was weak enough that it could not even repel.

Summary

Our project has allows us to experience superdiamagnetism and the Meissner effect. This allows us to demonstrate that the superconductor state is a state of matter to undergraduate physics students. The flywheel is a remarkable demonstration for physics students, able to demonstrate superdiamagnetism, flux pinning, the Meissner effect, and the concept of flux lines in three dimensions.

The attempts with the pendulum demonstrated that the design of the HTSC samples play an integral role in their application. The superconductors manufactured with crystalline irregularities allowed for the occurrence of flux pinning. This feature was highly favorable in the flywheel setup, but precipitated the apparent failure of the pendulums by opposing the anticipated push as discussed above. From here, further observations will be taken of the experimental setups we currently have established in efforts to quantify the force exerted by the flux pinning. The data we will collect in the upcoming observations will be included in the following report.

We will issue one additional report in the Spring once we've examined the pinning effects in different high temperature superconductors.

Budget

Item	**Cost ($)**
Liquid Nitrogen	Not Finalized
Dewar Flask	$468.00
Melt-processes HTSCs	Not Finalized
Low-pinning HTSCs	Not Finalized

Acknowledgments

Hegman, N. K Vad, S Mészáros, J Lindenmájer. (1997). European Journal of Physics. 19. p.259-264