Developing a capacitor-based system for permanent magnet magnetization

Abstract

Many robotics systems rely on permanent magnets, from Lorentz force actuators to magnetic imaging devices. However, permanent magnets are often expensive and there is little opportunity for customization. Machining unmagnetized magnets and then magnetizing them in a lab setting reduces costs and allows researchers to experiment with different geometries and magnetic field parameters. In the past, creating permanent magnets in labs involved unsafe high energy sources, such as arrays of lead-acid batteries. The goal of this project is to develop a capacitor-based system capable of creating magnets using much lower levels of stored energy, resulting in a safer in-house production process. Producing custom magnets will transfer important design decisions to individual researchers, enabling more innovative robotics systems.

I. Problem Statement

Many devices are dependent on magnets for proper function. Due to advancements in materials technology, permanent magnets are improving these devices. In particular, permanent magnets provide numerous benefits when used to make electric motors, as opposed to the more traditional brushed motors. Using permanent magnets in electric motors can result in higher power density and efficiency, improved motor response due to reduced inertia, and more reliable operation as a consequence of simpler construction. When designing devices that rely on permanent magnets, many different tradeoffs must be made, meaning that having control over the magnet production process is very important [1].

Neodymium iron boron (NdFeB) is a common material used for permanent magnets due to its high coercivity. The coercivity of a material is a measure of its resistance to changes in magnetization, thus a material with a large coercivity is able to hold a strong magnetic charge. NdFeB is relatively inexpensive, and when unmagnetized can be easily machined with a wire EDM machine. In this process, machining a specific shape for a magnet from NdFeB is relatively straightforward, but magnetizing a machined piece of NdFeB into a functioning magnet can be much more difficult. Magnetizing a piece of NdFeB requires a strong magnetic field in order to overcome the high coercivity of the material, and creating that field can be difficult and even dangerous. Permanent NdFeB magnets can be expensive to produce, especially if they need to be custom made.

In the MIT BioInstrumentation Lab, magnetic fields strong enough to magnetize NdFeB have been used to magnetize custom magnets in the past. The machine that was used to produce these magnetic fields relied on several lead-acid batteries connected in series. This system contained an enormous amount of stored energy, creating a very unsafe environment for researchers who interacted with the system. The goal of this project is to produce an alternative magnetizing system that uses lower levels of stored energy to magnetize permanent magnets more safely. The machine should be able to produce magnets of the same or better quality than what is currently produced commercially, and at a lower cost.

II. Related Work

Materials such as neodymium iron boron have high coercivity, allowing the materials to resist demagnetization. Unfortunately, this also makes the magnetization process more difficult as well [2][3]. In order to achieve magnetic fields that are strong enough to induce magnetization in materials like NdFeB, high peak magnetizing current levels are needed. Capacitor-discharge systems are generally used to provide these high peak currents in an impulse magnetizing process [4]. Designing an impulse magnetizing system that can magnetize magnets to fulfill desired properties can be difficult due to saturation and eddy current effects that take place within the material being magnetized. Nevertheless, simulation techniques based on finite element analysis have been developed to drive the design of impulse magnetization systems that depend on capacitors [3]. While capacitor-discharge based magnetizing systems exist in commercial production settings, there is little evidence that usable machines exist for use in a research lab setting.

III. Technical Approach

The proposed approach involves developing a semi-autonomous, capacitor-based system for magnetizing magnets. The system will use capacitor discharge as the power source for the magnetic pulse. Using capacitors instead of batteries as the energy store will result in lower total amounts of stored energy, thus improving the safety of the system. Since the system will be designed with the intention of magnetizing only a few magnets at a time, it will be well suited to making custom magnets cheaply. Importantly, most of the controls of this system will be automated to control the quality of the magnets and to make the system easy to use. Input power will need to be routed among the different capacitors in order to be balance charge levels. Furthermore, different magnetic loads may require different amounts of capacitors to be used, and the system should only use as many capacitors as needed. Power transistors controlled by a micro controller will be used to coordinate the charging and discharging process. The magnetizing system will also contain sensor feedback to ensure that the system is operating properly and to measure the quality of the magnets produced. Controlling the charging and discharging process along with summarizing sensor feedback will need to be done automatically by the system, to improve the ease with which users interact with the machine. Figure 1 shows a block diagram of the proposed system.

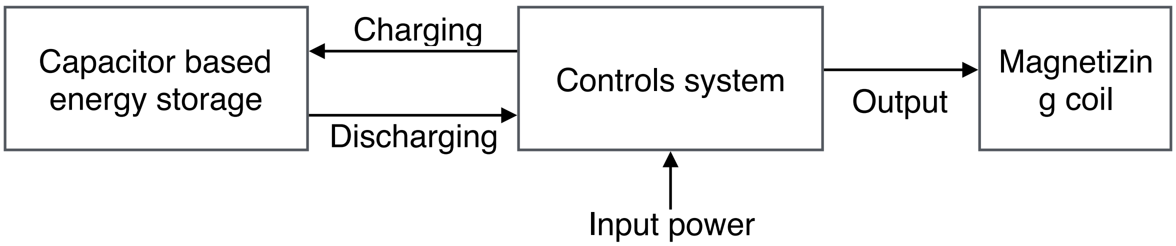

Figure 1: a block diagram of the proposed system. A capacitor-based storage system provides safety benefits over other possible storage systems, and the controls automates the system to make it cost-effective and easy to use.

IV. Expected Outputs

The main output of this project will be a magnetizing system. The system will take a standard wall-power input and unmagnetized neodymium iron boron pieces and will produce a magnetized permanent magnet. The cost of using the device will be low, and the quality of the magnets produced will be comparable to that of magnets produced commercially.

V. Evaluation Metrics

The magnetizing machine will be evaluated in three areas: cost, safety, and production quality. An important goal of creating this machine is to be able to create custom magnets at a much lower cost than purchasing from a manufacturer. Calculating the cost for creating a magnet with the magnetizer will be a clear way of determining whether this goal was met. Another important goal for creating the magnetizing machine is to magnetize magnets much more safely than with machines that rely on high-energy sources. The amount of energy that the magnetizer stores for each impulse will be one indication of the level of safety of the machine. Finally, the magnetizing machine needs to produce magnets of similar or better quality than magnets purchased from manufacturers. There are many different metrics that will be used to measure magnet quality, including residual induction, maximum energy product, flux, field strength, and field distribution.

VI. Conclusion

There is an increasing need for a method of producing custom permanent magnets. This process includes both the act of machining magnetic materials to make desired geometries, and also magnetizing the material after it has been machined. The magnetization process is currently controlled primarily by commercial sources, making mass production very efficient. Creating custom magnets, most commonly done in research settings, can be extremely expensive in contrast. At present, only unsafe systems exist to provide magnetization in a lab setting. This project will produce a magnetizing machine that can magnetize custom magnets at low cost, at high quality, and in a safe way.

VII. Project Timeline

Development of this system will first focus around creating a capacitor charging and discharging system. Next, a comprehensive control unit will be developed to coordinate the actions of the entire system. Finally, testing will be done to see how the system can be used to modify specific magnetic properties of permanent magnets.

Month	Deliverables
October 2015	Project Proposal Mathematical system model, with proposed circuit elements
November 2015	Combined capacitor energy module capable of producing the necessary power levels
December 2015	Poster Testing of capacitor energy module with old control system to magnetize a few permanent magnets
January 2015	New control system designed to work with the new machine
February 2015	Magnetize permanent magnets Initial testing results Refined machine design
March 2015	Analysis of magnetizing machine Initial tests from experimenting with magnetic properties
April 2015	Final test results of making magnets with the machine
May 2015	Paper

References

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[4] Riley, C. D., Jewell, G. W., and Howe, D., 2000, “Design of impulse magnetizing fixtures for the radial homopolar magnetization of isotropic NdFeB ring magnets,” Magnetics, IEEE Transactions on, 36(5), pp. 3846–3857.