YouTube Motor Lab for Electrical Engineering Students

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Abstract

This paper explores the use of the flipped classroom pedagogy in a laboratory course for third year electrical engineering students. The performance of a laboratory experiment to build and test a simple DC motor is discussed. It is well known from the flipped classroom setting that video clips of appropriate theory can enhance the learning, but using video clips to enhance the laboratory component of electrical and computer engineering course is much less reported. This paper describes how replicating one or two common YouTube videos can be used to enhance a student's knowledge of energy conversion principles necessary for the operation of a DC motor. Provided with a variety of components in the laboratory, the students must duplicate the construction and operation of a device they had observed on the YouTube video and demonstrate it to the lab instructor. This paper provides insight to the classroom experience, and includes an outline of the preparation, the experiment, the typical outcomes, and lessons learned.

Keywords

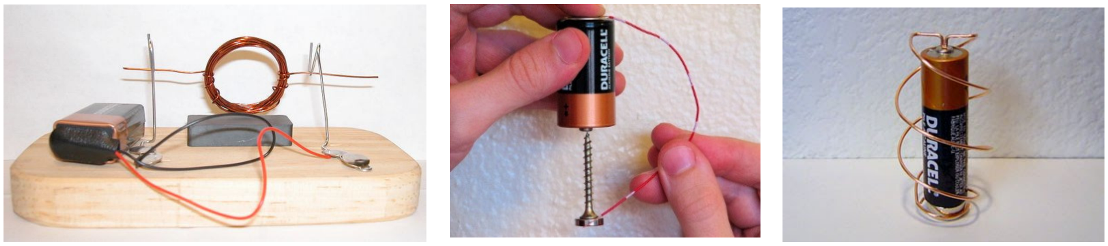
Flipped classroom, Electrical Engineering Laboratory.

Introduction

Many universities use some form of motor/generator platforms to introduce students to the concepts of electric machines. Both of the authors of this paper use the LabVolt system, but there are other similar systems. These units typically produce relatively prescribed laboratory procedures, such as: apply a voltage, set a torque level and measure a speed. While the procedure is quite repeatable, gives results that are quite consistent and allows the students a glimpse into motor/generator behavior, generally it is not very exciting or inspirational. It is granted that while excitement and inspiration are not always necessary for learning to take place, they certainly enhance the experience. It is well known from the flipped classroom setting that video clips of appropriate theory can enhance the learning [1], but using video clips to enhance the lab component of electrical and computer engineering labs is much less reported. This paper describes how replicating one or two common YouTube videos [2] can be used to explain and enhance a student's knowledge of energy conversion principles.

Lab Description

As part of a pre-lab exercise the students are asked to log on to YouTube and search for "Simple DC Motors" or "Homopolar Motor" in order to become familiar with some of the many interesting energy conversion devices that are in abundance on YouTube. Figures 1 a, b and c show some of the different varieties available to the engaged student.



a) Rotating coil b) Rotating wire c) Rotating spiral

Figure 1: Various simple DC motor designs on found on Youtube [2]

Each video runs for about 5 minutes or less and displays how a simple energy conversion device can be constructed. The students are tasked to assess several of these videos and select one they are capable of reproducing. They are also required to apply a more rigorous assessment as to what makes the motor work, which includes determining the direction of the magnetic field vector, sketching the magnetic flux path, determining the current path and applying the Lorentz force equation to determine where the rotational torque arises. Some of this information may be available on the video or on other similar websites, but not always. The students are expected to arrive at the lab with a working knowledge of the principles of operation of their selected design.

Handout Materials

Fortunately most of the motors available on the web can be imitated with a few inexpensive components. The students are told beforehand that they will get a length of magnet wire (we found that about 3 – 5 ft., or 1 – 2 m of AWG 23 wire works well), a battery (Size AA is good but 9V or even a small laboratory, current limited, voltage source works) and a magnet or two. Additionally, you may have on hand a selection of magnetic and non-magnetic paperclips, conductive foil, magnetic nuts and bolts of various sizes and possibly iron filings (although these can make a mess of your lab if not controlled very carefully). The first choice for magnets is neodymium because they produce a strong magnetic field and they are conductive. However, when working with NdBFe magnets the authors find it necessary to remind the students of (and strictly enforce) safe handling practices of working with strong magnets. This often results in the students wearing safety glasses (possibly for the first time) when handling these magnets. Ferrite or ceramic magnets are cheaper and are less likely to produce violent attractions and splintered magnets, but produce much weaker fields and are not conductive. The conductivity aspect can be fixed by wrapping the ceramic magnets in either copper or aluminum tape. This simple collection of materials combined with a few simple tools (wire cutters, insulation stripper, soldering iron etc.) makes for a very "hands-on, creative learning environment for students.

Lab Instructions

Students were told that they were to duplicate the device they had observed on the YouTube video and demonstrate it to the lab instructor. They were then asked to make modifications to the design, which would improve the performance of the device in a measurable way. The performance improvement could be in terms of torque, speed, improved starting, smooth operation or any other way in which the student could measure and report. Student were also requested to present a theory as to why the improvement occurs in terms of electric, magnetic, mechanical or material improvement. The lab instruction-set is a critical feature in providing the students with a context for learning and provides a means to guide the students through the exercise. If the instructions are too prescriptive the students receive less of the “cool! I built that!” response, however, if the lab is too open ended there is less understanding as to why a particular feature did or did not work.

Lab activity

Students come to the lab reasonably well prepared with an understanding of the design they wish to duplicate. The most common of the designs chosen by students are those pictured in Figure 1a and 1b. The students are less prepared in their knowledge of what the magnetic flux pattern looks like and exactly how the forces are generated. Most of their diagrams are quite vague, showing flux paths that are “almost” right but not specific enough to understand the behavior properly. A few moments of instruction highlighting the most common design configurations at the outset of the lab helps the students to better understand what they are trying to accomplish. They eagerly set to work creating their energy conversion spectacles and unless they have had some “maker” experience (which many have not had) they run into a series of troubles. These are described in the next section.

Problems Encountered

As the motors start to take shape, it becomes obvious that there are several deficiencies in the student understanding of how the motor is supposed to work. This is particularly true for motor a) of Figure 1.

Commutation: The motor of Figure 1a requires some form of commutation, which usually takes the form of stripping one side of the magnet wire insulation bare and leaving the other side insulated. Stripping the wire only requires a sharp edge and can even be accomplished with wire insulated with thermo-plastic insulation. Some of the students are aware of this problem, but many still don’t understand the special relationship between the position of the coil and the point of electrical contact. Moreover, problems with commutation can be reduced if one end of the wire is completely stripped and the other end only partially stripped, thus allowing the commutation to take place on one end only.

Winding Balance: Students soon discover that getting the rotating winding to balance properly can be difficult. Motors of the Fig 1a variety need to be able to rotate smoothly about their axis. With hastily wound coils students find this balance hard to achieve. For motors of the Fig 1c variety, getting the loop to balance on the top of the battery often requires multiple minor adjustments to get the combination of rotational balance and electrical contact to work together effectively.

Bearing design: Similar to the balance problem encountered by students, designing a stable bearing platform was also an impediment to smooth motor performance.

Student Reaction

For the vast majority of the students, they were able to complete the task of making a functioning DC motor. This usually brought a sparkle of joy to their eyes and a sense of accomplishment.

They had a better understanding of the fundamental principles and were able to grasp the more subtle implications of more advanced machine design. Many of the student course evaluations mentioned the great experience with this lab session.

Learning Objectives and Outcomes

The lab objective is to promote learning in five significant areas as follows:

Magnetics - Students learn how to apply their understanding of magnetics to real-life situations. This includes not only determining how electromechanical energy conversion devices work but how to use additional magnetic resources to improve and enhance a specific design.

Mechanics- Students learn how the mechanical components of energy conversion devices play an important role in the overall operation of the device. Bearings, balance, cogging, and symmetry all are experienced first-hand as part and parcel of a good design. Seeing how dependent good electrical design is on good mechanical design helps break down the “silo” thinking and helps the students see the interdisciplinary aspects of the devices they will be designing in the future.

Electrical- Students learn about the use of magnetic wire and to understand the concept and purpose of insulation. Typically, several groups try to wind bare copper wire into a coil not understanding that the turn-to-turn insulation is what makes a coil so effective. Other groups think that just because it has a copper hue, then it must be copper and do not realize that the wire must be stripped of its coating in order to provide electrical contact.

Student Research- Students are able to find sufficient YouTube content to prepare them for the lab. They generally know what design they want to try to imitate and they have a vague idea as to how they might try to improve that design. The research component that is least well done is the concept of how to apply their understanding of magnetics and the various forms of the Lorentz force law to the specific design they are interested in. Since we are specifically instructing the students to “copy” someone else’s idea, this lab provides another opportunity to discuss academic integrity and appropriate methods to reference existing literature. The concept of researching on-line content for useful ideas also contributes to developing lifelong learning skills not to mention the necessity to evaluate Internet content for veracity.

Manual Dexterity- Students are provided the opportunity to build and improve their manual dexterity skills. While they may not leave the lab with enhanced skills they may at least have a greater appreciation for those who do have those skills. Considering most engineers will have to work hand in hand with skilled trades workers, this is not something to take lightly.

Measurement

One of the fascinating aspects of this lab exercise, and one that was not expected in the first pass, was the opportunity the students were presented with to think through a measurement problem. If the motor is built with any precision it will spin faster than the eye alone can measure and therefore in order to assess performance, and any improvement gained, a measurement system becomes necessary. Students are challenged to find ways to measure the speed of rotation of the coil they have just built. Each of the various designs has their own unique challenges. The design of Figure 1 a) tends to produce high speed rotation and thus more difficulty in making a speed determination. Optical sensors can be made available for the students but unless the lab instructor predesigns them, it tends to drag the lab down and the students get lost in electronic issues. One easy method that presents itself is simply to monitor the battery voltage and display the results on a storage scope. Figure 2 shows typical results indicating that a commutation spike takes place approximately every 0.1 second. This yields a rotational speed of about 11 cycles per second or 660 RPM.

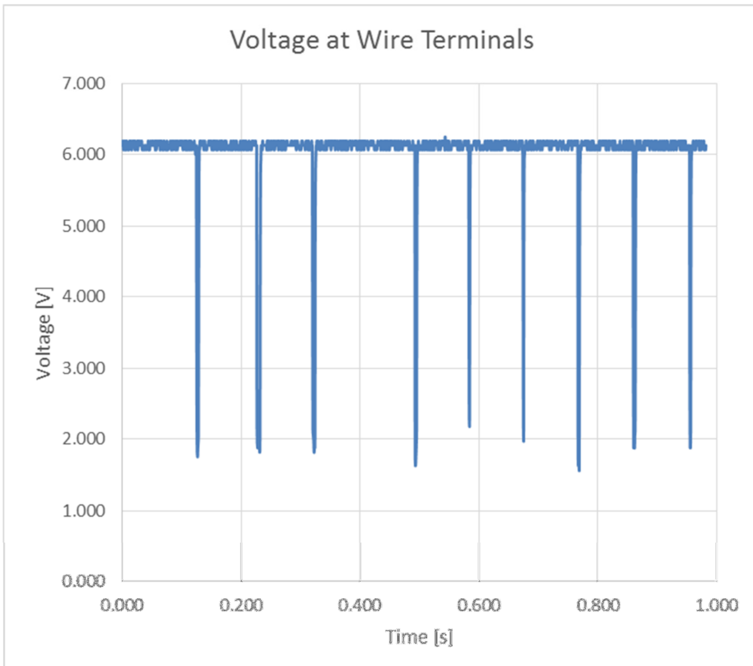


Figure 2: Simple DC motor battery voltage vs. time for determining motor speed.

Lab Improvements

To get the most out of this lab, there are several things that can be done to prepare the students both before during and after the lab in order to maximize the learning potential.

Pre-Lab Training- In addition to finding and watching the videos, students should review the basic physics of homopolar motors such as described in ref [5]. An understanding of the principles of operation such as the Lorentz forces and right hand rule will be of fundamental importance.

In-Lab Exercises- Depending on what equipment is available, exercises to plot or calculate the magnetic flux density patterns can be extremely useful. Finite Element Method (FEM) software can be used either by the students or by the instructor to solidify the understanding of magnetic fields. Using flux density sensors (if available) to empirically plot the flux density in the space surrounding the magnets can augment this. Something as simple as a balanced wire loop with a defined current and counter-weights can help the students better understand the magnetic field properties

Pre-built Structures- Several pre-built structures could be used to improve the overall performance of the motor. One feature would be to provide a stable set of bearings on which to place the rotor. Providing appropriate shapes for producing windings would also enhance the product. These could be rectangular or circular geometry that might match the magnetic field more closely to maximize the force production. As noted above an instrumentation system for measuring speed removes the measurement problem and keeps the students attention focused on the energy conversion problem if desired. The speed measurement system can be reserved until the students have had some time to think about the measurement problem and propose their own solutions.

Conclusion

The authors have presented their experience in a new energy conversion lab that incorporates hands-on, empirical conceptual learning for fundamental principles of electromechanical energy conversion. The lab is fun; it builds “maker” skills and brings a sense of satisfaction to the students who participate in it. The lab can be run very cheaply with low cost components and many components can be used year after year.

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