Experimental Education: Design and Implementation of Nikola Tesla's Egg of Columbus as an Instructional Aid

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Abstract

This paper describes the on-going efforts to create a two-phase induction motor to serve as an educational and instructional aid for demonstrating various concepts in physics and electromagnetism for students and visitors to Florida Polytechnic University. Specifically, the mathematical calculations required and design process used to create a functioning two-phase alternating current induction motor similar to the Egg of Columbus (EOC) machine created by Nikola Tesla will be explored. In addition, physical aids may be constructed to demonstrate the fundamental physical and electromagnetic principles supporting the overall function of the induction motor. Further, surveys may be created and distributed among students to gauge the effectiveness of the experiments in comprehension of the fundamental concepts and, thus, effectiveness of the model as an instructional aid. Finally, efforts will be made to ensure this project is scalable, so that future students may expand upon this experiment as deemed necessary.

Background

Many institutions of higher learning possess their own Tesla's Egg of Columbus device or other functional examples demonstrating the principles of the induction motor as invented by Nikola Tesla in 1888. As a new Science, Technology, Engineering, and Math (STEM) university, Florida Polytechnic University strives to conduct their own similar experiment for both the purposes of exploring the phenomena and mathematics required to recreate a Tesla's Egg of Columbus mechanism and for exploitation as a learning tool for other students.

Apart from individual institutions of higher education, there are other organizations that maintain the advancement of engineering education in general as one of their goals. For example, the American Society for Engineering Education states this as their primary goal, which they strive to achieve through, "promoting excellence in instruction, research, public service, and practice; exercising worldwide leadership; fostering the technological education of society; and providing quality products and services to members"[1]. In addition, the well-known Institute of Electrical and Electronics Engineers (IEEE) has its own Education Society, which maintains as its mission the "focus on the theory and practice of education and educational technology involved in the effective delivery of domain knowledge of all fields within the scope of interest of IEEE," in addition to sponsoring the IEEE Global Engineering Education Conference (EDUCON)[2]. It is clear that engineering education is a topic of fundamental importance to not only institutions of higher learning, but also to several diverse organizations across the world.

If we accept that the education of engineering concepts is of global importance, then by extension we may conclude that the methods used for this education (or the pedagogy, specifically) carry equal or greater importance, as they directly impact the effectiveness and quality of the education provided. Traditional "chalk and board" methods of instruction are widely accepted as effective for the broadest spectrum of subjects; however, this may be attributed in large part to the practical availability of this technology. In addition to chalkboard method, there have been studies conducted that support the use of audio-visual (AV) aids (e.g., PowerPoint slides, physical models, labs, etc.) as an effective way to not only teach, but strengthen the pupil's comprehension of the target material and concepts. In one such study, it was found that the respondents viewed that AV aids play an important role in the learning process from the perspective of both the teacher and the student[3].

More important than the perception is the reality; how do AV aids effect the actual comprehension level of the student compared to that of traditional learning, especially in science and math subjects? In one particular study, results showed that "both [model-based inquiry] and [model-based inquiry in a virtual physics laboratory] were more effective in developing student scientific inquiry skills compared to the traditional learning model, especially in the dimensions of process skills, comprehensive skills, learning attitude, communication skills, and reflection skills"[4]. Model-based inquiry can be defined as "a process in which students develop questions and procedures, carry out experiments, and generate and communicate conclusions in an effort to explore various phenomena and construct and reconstruct models based upon results achieved by scientific investigations"[5].

Instructional Aids

With the acceptance of the model-based and audio-visual aid pedagogies, we endeavor to produce several instructional aids spanning these spectra. There are many fundamental, core electromagnetic concepts that can be observed in the basic EOC model: creation of a magnetic field through current, creation of current through a magnetic field, electromagnetic induction, eddy currents, gyroscopic effect, physical and magnetic torque, to name a few. A few key concepts that directly explain or are related to these phenomena include Faraday's Law, Lenz's Law, the Lorentz Force, and, of course, Maxwell's equations.

To these, slides will be created to accompany the EOC in an effort to visually explain each of these concepts as simply as possible. In addition, helpful tools such as the diagrams portraying right-hand rules for determining the direction of the current, magnetic force, and magnetic field in a wire and in a loop, for example, will also be introduced. These would be utilized to prepare the student regarding the behaviors they should expect to observe, followed by actual demonstrations. They can then be used to compare their expected outcomes with the actual observations.

For example, some of the fundamental concepts, such as Lenz's law, can be first taught through the use of slides and graphic representations. Students may then be asked to hypothesize the outcome of passing current through a wire when wrapped around a coil. Further, they may be asked to calculate the resulting magnetic field strength based on a predetermined amount of current, length of the conductor, and number of turns of wire around the conductor. The actual result can be easily observed by passing a predetermined current through one simple iron bar wound with coils of copper wire, through which a current is passed to produce a magnetic field.

Students and observers can also be asked to determine in which direction the magnetic field will be oriented and immediately test their hypotheses through the use of a nearby magnetic compass, for example. Further, by reducing or increasing the number of coils, the effect on the resultant magnetic field can be immediately observed, teaching and reinforcing key principles of electromagnetic fields.

Tesla's Egg of Columbus: Two-Phase Induction Motor

Our EOC model concept essentially utilizes an iron core toroid divided into four sections wound with a specific gauge of copper wire for a specific number of turns that, when alternating current is applied, will produce a magnetic field around the toroid. The interior portion of this field (i.e., the "leakage field") should serve to create eddy currents on the surface of a hollow brass egg placed on a smooth surface in the center of the toroid. These eddy currents, in turn, produce their own magnetic fields which, upon interacting with the leakage field of the toroid, should initiate and sustain the rotation of the egg in the center of the toroid through the opposing magnetic forces (torque). The egg will increase its spin over time with such angular momentum as to leverage the gyroscopic effect and, eventually, rotate on its smaller end.

Drawing largely from a 2014 study conducted by the University of Banja Luka and presented at the Tenth International Symposium for Industrial Electronics (INDEL)[6] for guidance, we endeavor to recreate the two-phase alternating current induction motor introduced by Nikola Tesla using an iron core toroid as a stator and a hollow brass egg as the rotor. The toroid consists of four separate sections physically offset by 90 degrees, with each set of two opposing sections serving as one phase. Each set is wound with a specific number of turns, layers, and gauge of copper wire. When alternating current is applied to each of the two phases, offset by 90 electrical degrees, a magnetic field is induced; this field within the center of the toroid (the "air gap"), can be utilized to produce a magnetic torque on a hollow brass egg, thus causing it to spin. Over time, the egg will spin such that it will rotate on its smaller end due to the gyroscopic effect.

Many factors affect the quantitative properties of this experiment; we therefore made a few assumptions to begin the mathematical design process. For example, assuming a magnetic flux density of 10 milli-Tesla (mT), an ambient temperature of 24° C, and an operating temperature of 80° C, we calculated that 20-gauge copper wire using 3 amps provided by a 120-voltage source in one phase would require 616 turns over 4 layers, while the second phase would require 2.75 amps through 673 turns of wire. As the initial assumptions and their dependencies are inherently variable, we created a spreadsheet that accounts for changes in many of these variables, thus providing updated quantitative results every time one or more assumptions are altered. This tool is not only helpful for the design process, but instrumental in teaching the effect of altering one or more variables on the overall performance.

The principal formulas used to determine the specifications for the EOC model will be provided in Table 1 and listed in chronological order. Subsequently, the symbols and values used for the standard constants and variables required for these calculations, along with a brief description, will be provided in Table 2. However, a preliminary block diagram showing the proposed configuration of the power, control, and toroid is depicted in Figure 1.

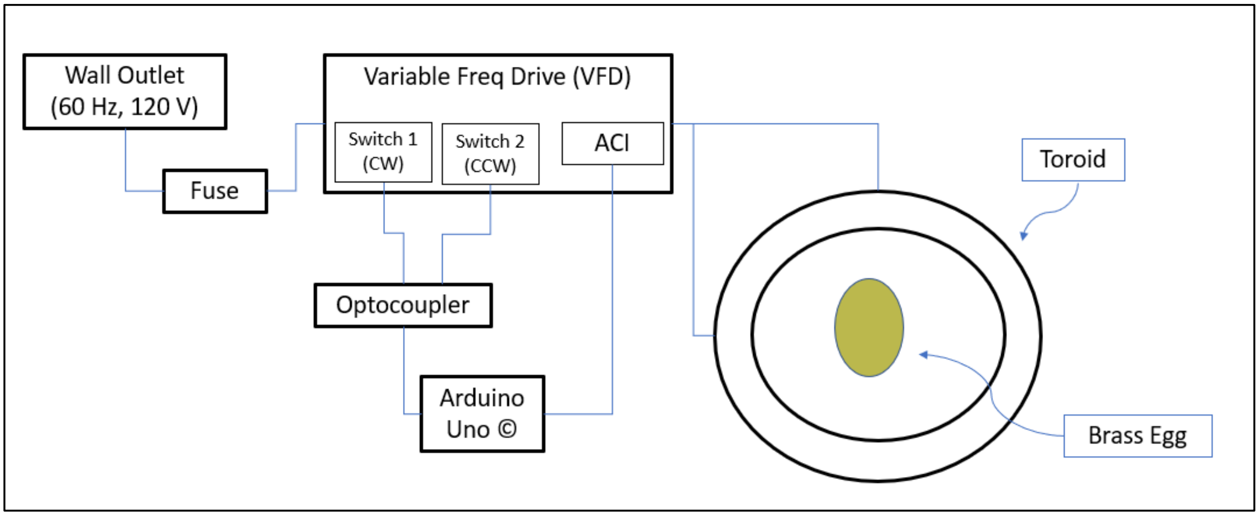

Figure 1. Proposed configuration.

The design of the egg itself proved very challenging; as a new institution, FPU doesn't currently possess the facilities and equipment needed to produce such an object. Although one potential egg for use in this project was located and procured from an online vendor, this egg was estimated to be approximately twice as large and heavy as most eggs observed in other similar projects. If utilized for this experiment, it would necessitate considerable modifications to the magnetic field strength required in order to function properly, which would drive the need for more wire and a larger toroid and supporting base, at a minimum. Therefore, the researchers intend to design their own egg using SolidWorks, a 3-D CAD program, with the goal of outsourcing its fabrication to a local company with CNC capability. To both simplify the process and provide some level of predictability of performance, the dimensions and design of the egg as specified in a 2016 study by the same institution, University of Banja Luka[7], may be referenced and utilized in our design.

Some ways in which we endeavor to differentiate our experiment form others is to calculate the torque acting upon the egg given certain initial assumptions, factor in thermal considerations, and create additional physical design components that enhance the learning experience for demonstration purposes (e.g., digital displays or sensors that reflect the magnetic reading at different stages and/or points, temperature of the coils, etc.).

Future Work

Finally, efforts will be made to design this experiment with the ability to scale and expand upon its base structure, providing for potential additional tools, displays, etc., that may be desired by future students. Surveys provided to students and observers over time should provide key insights as to ways in which this experiment can be improved to more effectively relate the key concepts intended; however, some suggestions are provided in this paper.

One obvious way in which future students may enhance the instructional potential of this project is to augment the device with a method for controlling the frequency of the alternating current and, thus, the speed of the rotating magnetic field. This would allow for more clear observation of the effects on the rotational speed of the magnetic field with respect to the frequency of the alternating current. Some students may be able to leverage their knowledge of electronic circuits in order to construct a variable frequency drive, for example. Another method which may be explored might be through the replacement of alternating current with direct current through the wires and the use of pulse width modulation (PWM) to simulate an alternating current. None of these methods would require adjustment to the physical design of the base or the motor, however.

Another way in which modifications for instructional purposes may be made involve the control methods. Further control methods could be explored by connecting sensors and microcontrollers to the circuit in order to observe the effect of manual increases and decreases in the amplitude of current being passed through the system on the strength of the magnetic field. Controls may also be used to adjust the currents automatically based on the coil temperature; this would help to ensure the coils neither pose a safety hazard through overheating nor lose sufficient conductivity in the wires as heat creates resistance, which would eventually reduce the strength of the magnetic field and the motor's operation.

In sum, we reviewed and leveraged several previous sources in an effort to create a working two-phase induction motor similar to that created by Nikola Tesla in 1893, with the overall purpose of enhancing the educational experience and enable more effective comprehension of the underlying physics and mathematics principles of critical electromagnetic concepts. We put effort into designing our model to be scalable and adaptable to potential future needs and desires of Florida Polytechnic University students and faculty. With this in mind, pre-test and post-test surveys should be initially and periodically conducted for the purpose of gauging the efficacy of these models and instructional aids. Future students and/or committees may then adjust these models and aids as deemed appropriate. This work is on-going and will be reported on again upon, if not before, completion.

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