FINAL REPORT: December 20, 2010

MEASUREMENT OF AN INDUCED ELECTROSTATIC FIELD ABOVE A ROTATING MAGNETIC DISK

SPS Chapter: Western Illinois University

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Abstract:

It is commonly understood that the rotation of the magnet in a Faraday generator is immaterial. We propose to conduct precise measurements of the electric field above a rotating magnetic disc and show whether or not the rotation of the magnet does induce an electric field.

Final Report (December 20, 2010):

Outline and Summary:

We were awarded $800 by the national SPS to design, construct and test an apparatus that would allow us to show whether or not a rotating magnetic field induces a radial electric field. The apparatus that we constructed fell short of the design specifications in several important ways, and we were unable to measure any induced electric field due to the rotating magnetic flux. Nevertheless, several important benchmarks were established to help reach the stated goal. The most important of these was the viability of making a direct measurement of the induced electric field arising from a rotating magnet using the miniature cylindrical mill electric field sensor. We believe that with only a slightly greater investment in the materials and construction of a rotating assembly, a definitive measurement should be possible.

Budget and Expenses:

The equipment listed in the original proposal for this device was obtained, at the following cost:

China Magnet Source (N42 NdFeB magnet)	$177.60
State Electric Company (Bodine A24 motor)	$201.05
State Electric Company (KP DC control, switch, resistor, fuse)	$203.12
VXB.com (2 hybrid ceramic/stainless steel bearings)	$144.35
McMaster/Carr (12 in long, 7 inch diameter cast nylon rod)	$142.97
Shipping Costs for Electric Field Sensor	$6.97
Vibrationmounts Flexible Spline Coupling	$25.98
Total	$902.04

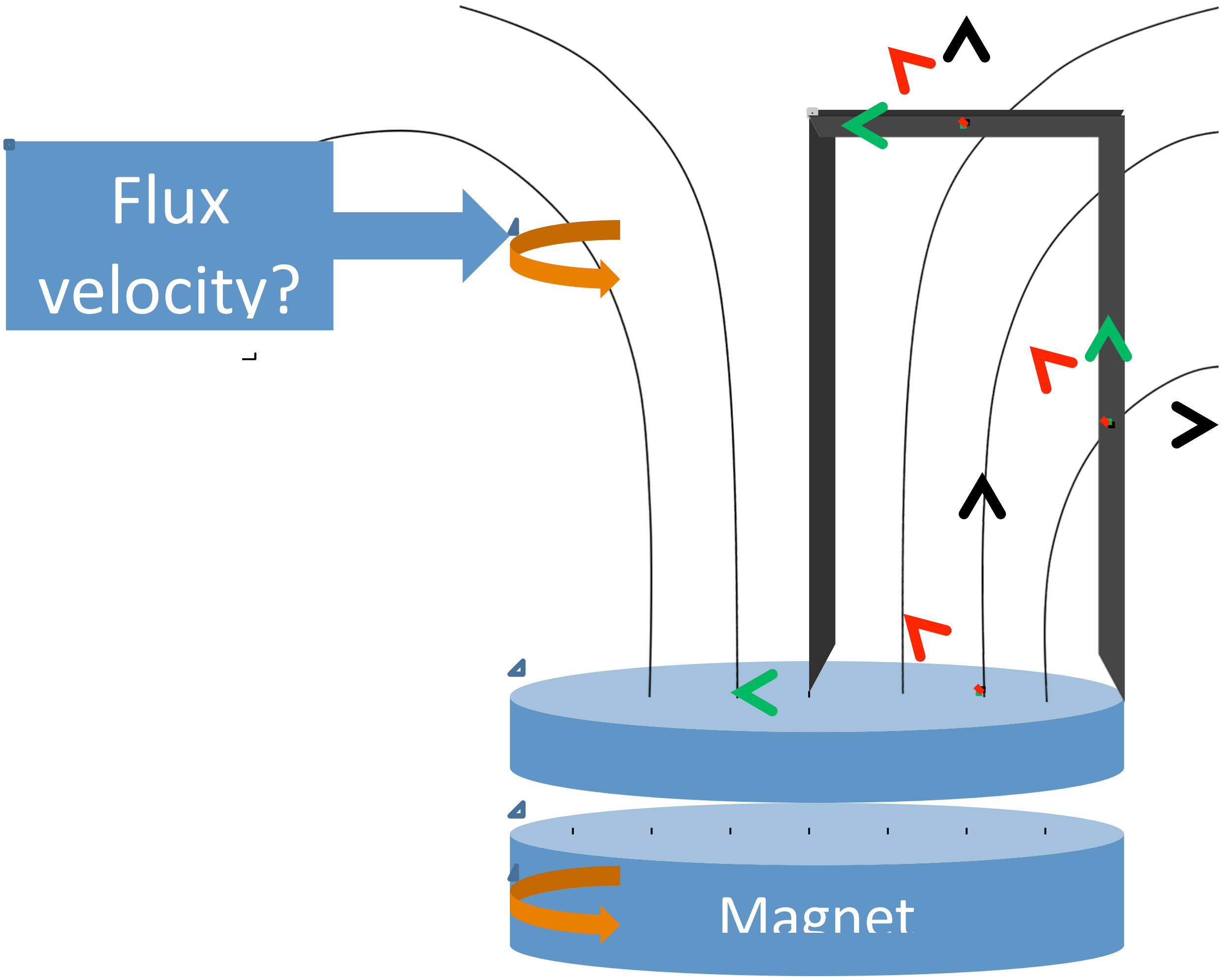
This is to be compared with the funding provided by the SPS of $800.

The Physics department supported the project with end-of-the-year funds to help pay for the bearings and nylon rod. The researchers at the University of Michigan sent the sensor and graciously allowed us to use it till the middle of June, when it became apparent that our rotating assembly would not be able to come close to the required rotational rate. They also didn't charge us at all for packing or shipping the device, which saved us quite a bit of money. The department of Engineering Technology at WIU donated labor and equipment for the machining of the rod and frame. Jim Rabchuk purchased the spline coupling and motor fuses out of pocket.

Device Design and Construction:

The goal of this project was to create a device that would spin a large cylindrical disk magnet at a high enough rate to observe whether or not a radial electric field was induced above the magnet's surface. If such a field were observed to have the predicted radial orientation and dependence on radial distance, it was proposed that the best explanation for such an electric field would be from the *v X B* term in the Lorentz force, with the novel interpretation that the velocity in the expression is the tangential velocity of the source of the magnetic field, that is, the magnet itself. This result has been suggested by the work of Kelly (Kelly, 1999) and Guala-Valverde (Guala-Valverde et al., 2002) on Faraday generators and Homopolar Motors. But this would be the first time that an induced electric field would be observed as resulting from a magnet rotating about its axis of symmetry. And it would suggest that the rotation of the magnet imparts a velocity to the magnetic field lines emanating from the magnet. If that is the case, it suggests that magnetic flux is a physically real phenomenon which has demonstrable properties separate from those of the magnetic field. It may even suggest that magnetic field is a derived quantity, while magnetic flux is the more fundamental quantity when considering sources of magnetic interactions.

The magnet and flux rotate but the forces cancel out



No current is induced anywhere because all the fo
caused by the moving flux over a closed circuit ca

Figure 1: The common explanation for how a Faraday Generator works is that the induced emf arises from motional emf. In this picture, the motion of the magnet is irrelevant. But perhaps the effect of the rotation of the magnet is simply canceled out?

The initial design of the device was put together by Chris Fraser and Dustin MacDermott in consultation with Dr. Jim Rabchuk. The motor purchased was rated as having a top rotation rate of 11,500 rpm. The bearings purchased were rated at having a top rotation rate of 17,000 rpm. The plastic case was cut from a single vinyl cylinder of 7.0 inches in diameter and 12 inches in length. The piece was trimmed as much as possible to reduce mass, and then cut and hollowed out to make room for the 6 inch diameter NdFeB magnet. The side of the case facing away from the motor was trimmed to a thickness of 0.1 inch to provide as close an access to the surface field of the magnet as possible. As much as possible we avoided using metallic parts to prevent any interactions with the magnet either through magnetic attraction or through eddy currents. An aluminum cup was designed to couple with the motor, for structural integrity. The bearings were a hybrid of a steel case, nylon races and ceramic balls. The top and bottom portions of the frame were made of ironwood. The side pieces were made from scrap, high density plastic. Half-circular sections were cut from the sides of the side piece away from the magnet, to provide greater access to the magnet surface for measurement. Measurements could be made as close as 3.9 cm to the center of the magnetic disk.

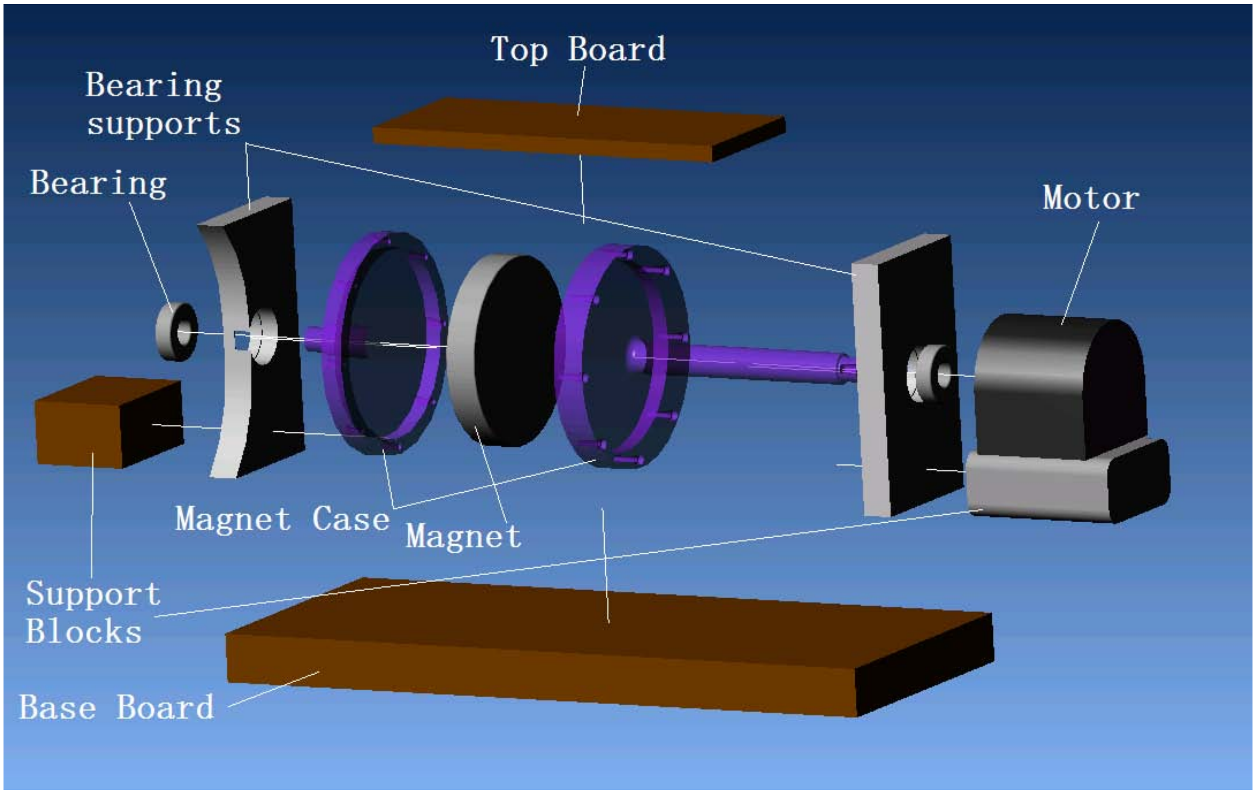


Figure 2. The original design for the rotating assembly and magnet

Assuming in the ideal case that the magnet's magnetic field was perpendicular to its surface, and that the magnetic flux is given a tangential velocity equal to ωr, we could expect to see a radial electric field of $\vec{E} = \omega r B\hat{r}$, and at the edge of the magnet rotating at the highest possible speed, we should be able to measure a field of magnitude: E = (2 π * 190 rev/s) (0.075 m) (0.3 T) = 27 V/m. This field strength is at the limit of the ability of the miniature electric field sensor to detect. However, it is supposed that by measuring the field on opposite edges of the magnet, where the field should be pointing in opposite directions, the difference in the measured field should be enough to make a definite observation of the induced E field.

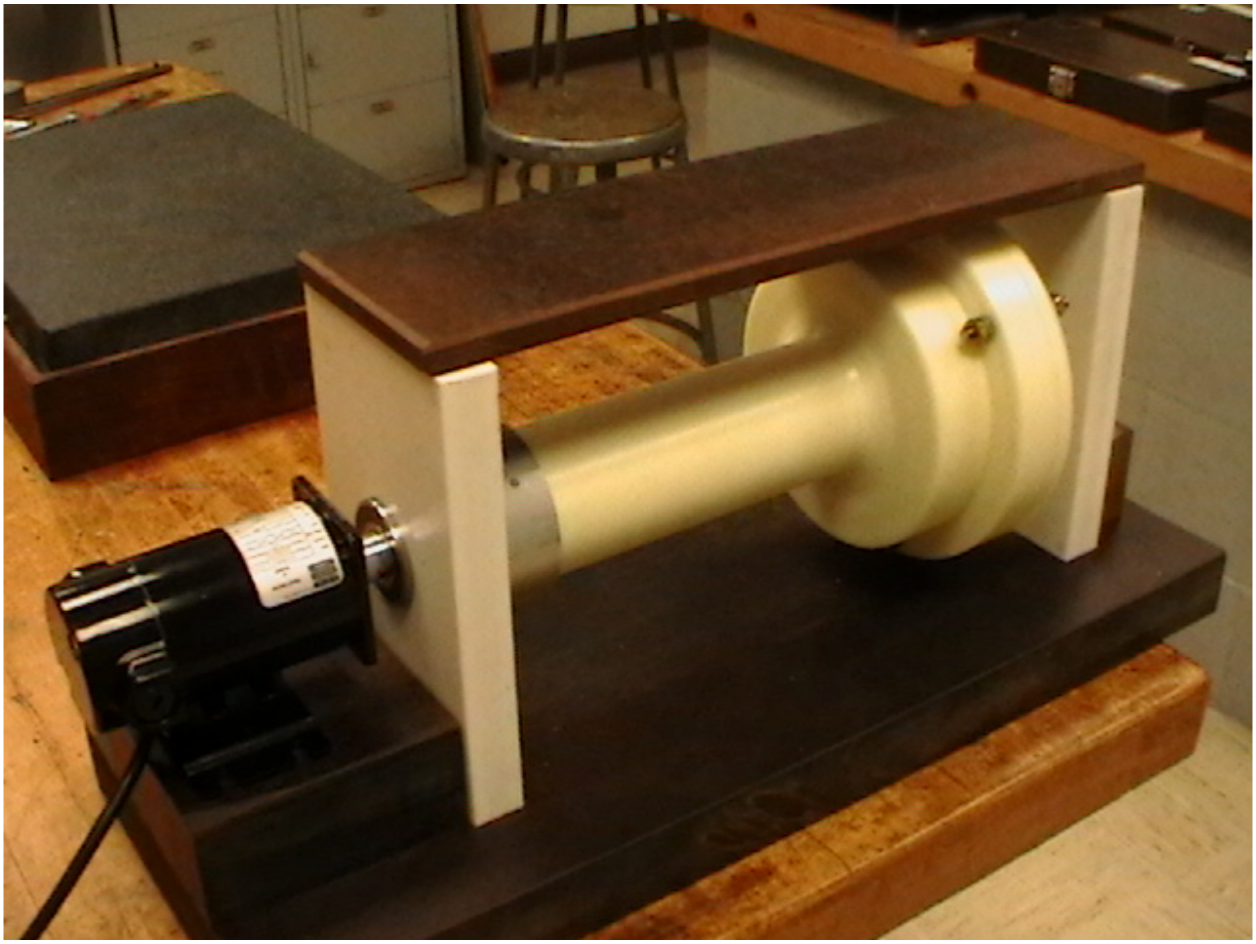


Figure 3. The assembled apparatus. Later, holes were cut into the backpiece to allow easier access the magnet surface. Also a spline coupler was used to couple the motor shaft to the assembly.

The construction of this device proved to be the greatest obstacle to accomplishing the goals of this research project. Several issues conspired to reduce our maximum rotation rate from 11,500 rpm to roughly 1,000 rpm. Among those were the need to keep more mass on the plastic case of the magnet, the fact that the thin surface of the case where measurements were to be made began to warp due to the weight of the rest of the plastic, and the difficulty of balancing the entire apparatus so that the motor could rotate smoothly with minimal resistance. It is supposed that stronger plastic, a larger motor, and a more precise machining of the entire apparatus would enable us to meet or exceed the required speed for the rotation of the magnet.

The Electric Field Sensor:

As shown above, the magnitude of the induced electric field even for a large magnet is quite small, on the order of 30 V/m. It is for this reason that the phenomenon underlying Faraday Generators is typically observed by measuring an emf within a closed circuit, since in contrast to the electric field, the electric potential generated is a cumulative effect, and therefore much easier to observe. However, it is an observational fact that part (but NOT ALL) of the circuit needs to be in motion with the rotating magnet to observe the induced emf. This makes quite difficult using the Faraday generator concept to demonstrate whether or not the motion of the magnet is essential. Nevertheless, Guala-Valverde, et al. did just that by introducing a small reversal in the magnetic field in order to distinguish motion of the connecting wire in the Generator from that of the rotating plate. But there is no direct confirmation that the rotation of the magnet by itself induces an electric field. Therefore, a meter capable of detecting such small electric fields was crucial to the viability of this experiment.

The probes developed by Renno, et al., at the University of Michigan, were identified as the best candidates for doing so. The miniaturized version of their probe has a sensor that is 2 cm long and 1 cm in diameter. It was calibrated at Lawrence Livermore Labs, and shown to have a sensitivity of 10 V/m. The probe is shown in the images below. The sensing surface is shown in the figure on the right. It consists of a conductive material covering the cylinder's surface, and then separated by small strips into two half-cylindrical shapes. The probe in operation is rotated at 1800 rpm, and the fluctuating current between the two half-cylinders as the probe is operated in an electric field gives information about the field magnitude and direction perpendicular to the shaft of the probe.[2] The plastic piece on the end of the probe is for recharging the battery inside the rotating portion of the probe.

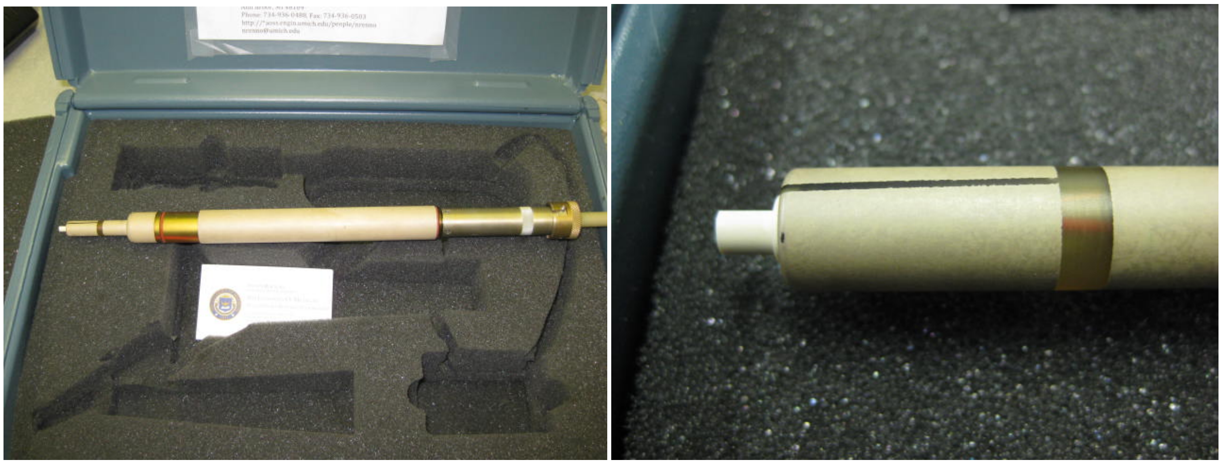


Figure 4. The miniature cylindrical mill electric field sensor.

The electric field sensor was connected to a nearby computer using a serial port connection. Renno provided us with the software required to operate the sensor and also supplied a program written for the software SciLab to analyze the data. This program was modified to allow for averaging over longer periods of time to reduce the influence of stray fields. The sensor was tested by measuring the field between flat plates at various separations and voltages, and shown to be accurate down to ~ 10 V/m. The probe was then run in open air and in electrically-shielded environments to determine what the appropriate background reading. This turned out to be a very challenging measurement. Eventually, it was established that if one were very careful, it was possible to obtain readings of 5 to 10 V/m as background. This became more difficult when physical objects such as the rotating assembly were nearby. In these cases, a reading of 15 to 25 V/m were more common for background, meaning that the signal from the rotation would be just above background. For this reason, it would be necessary to take a difference between two measurements on either side of the probe to see the signal clearly.

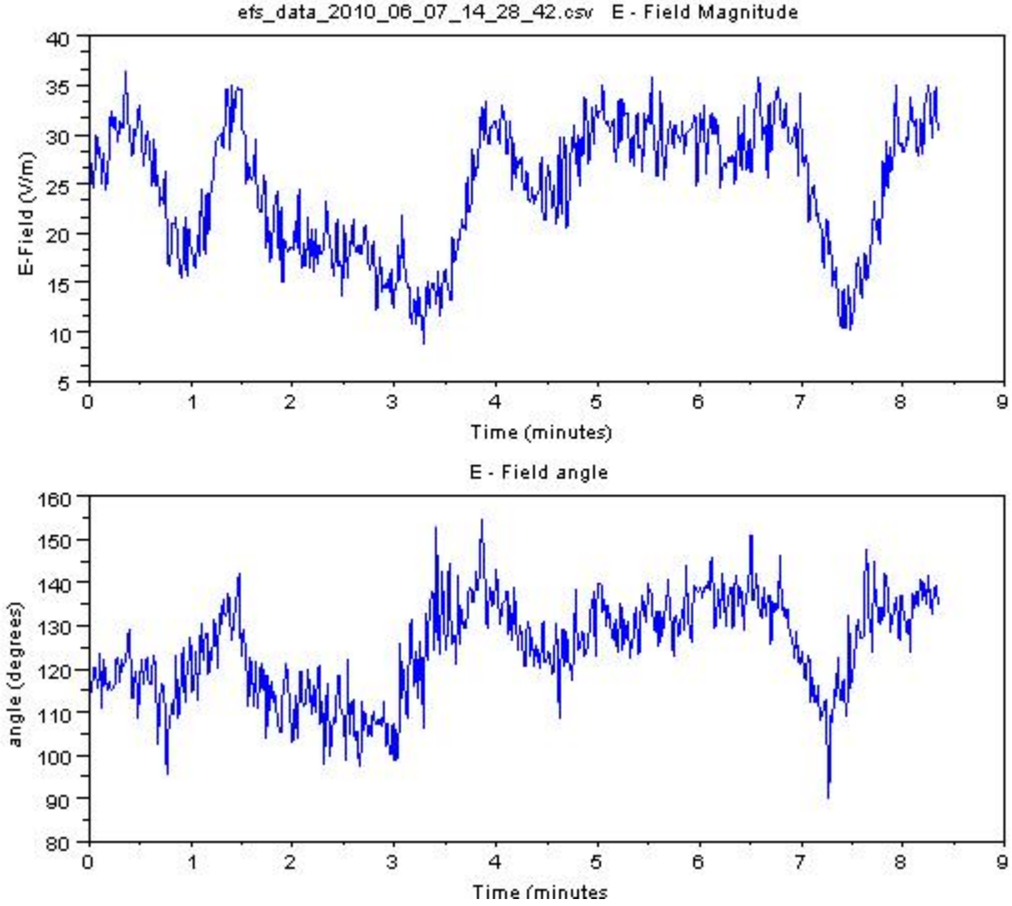


Figure 5. Electric field measured at the edge of the magnet, and .3 cm from the plastic case, but with the magnet not inserted.

The following two sets of graphs are of data taken with the electric field sensor for the device with the magnet in place, but at rest. The sensor is placed a distance of 0.3 cm from the thin plastic side covering the magnet, and at a distance of 7.5 cm from the center of the disk, and therefore directly in line with the edge of the encased magnet. The first set is for the sensor placed like this on one side of the apparatus, and the second set is with the sensor positioned on the opposite side of the apparatus. The primary thing to note is that the effective field (arising due to the component of the magnetic field that lies perpendicular to the axis of the cylindrical sensor and is a function of the radial position along the magnet's surface) is significantly above the background field, and that the measured fields at the two positions are pointing at angles that differ by ~180 degrees. The effective field due to the magnet is clearly distinguished from the background, shown measured at the same position, but without the magnet in place. The fluctuation in the signal is partly a result of some unwanted vibrations in the sensor due to resonance with the stand it was attached to.

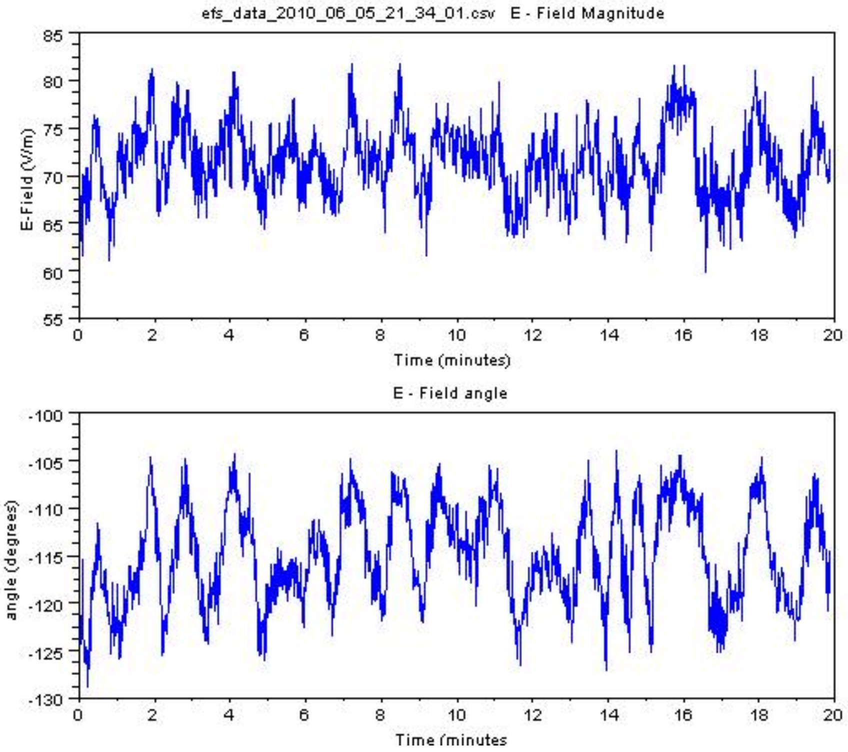


Figure 6: Effective electric field measured above magnet's edge on left-hand side of apparatus.

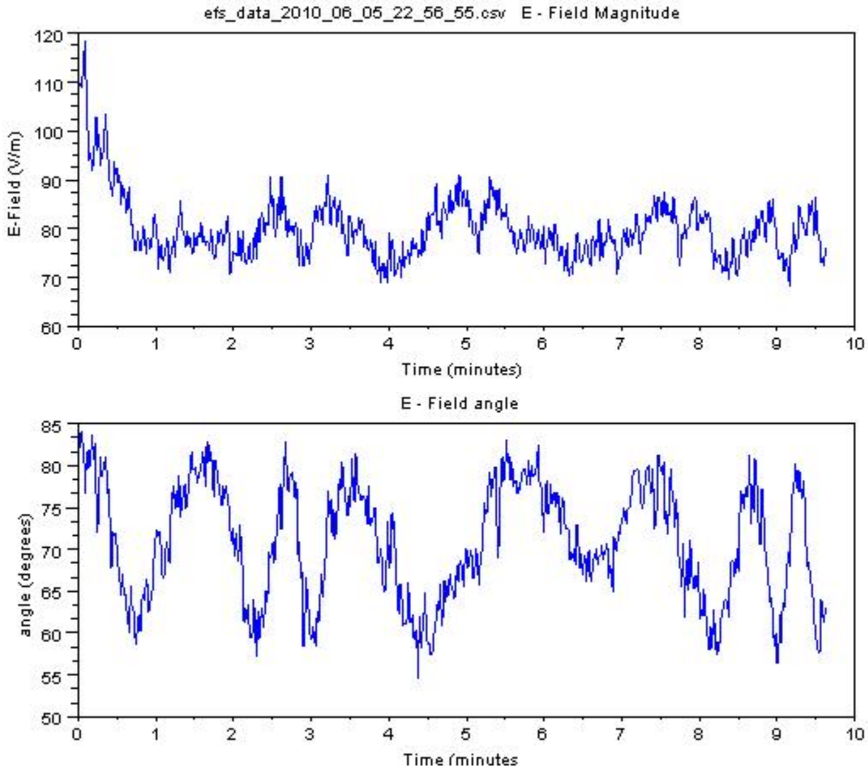


Figure 7: Effective electric field measured above the magnet's edge on the right-hand side of the apparatus.

Modifications:

Although it was possible to observe the effect of the magnet on the probe, due to ordinary motional emf resulting from the rotation of the probe surface in the presence of the magnetic field, it was clear that a rotational rate of 1000 rpm was not going to be enough to create an induced field that would be observable above the background. We would have to start over in constructing a better apparatus to accomplish that goal.

Nevertheless, another student, Jeremy Streater, helped modify the device to create a standard Faraday generator. He cut out a circular piece of copper from a scrap copper plate and affixed that to the rotating assembly just over the magnet. He also cut a smaller piece to fix over the end of the shaft, and then soldered a copper wire between the two sheets. We then measured the induced emf between the smaller copper plate and the larger one at the edge. The predicted emf for a device rotating above a 0.3 T magnetic field, at a rate of 1,000 rpm and of a radius 7.5 cm is $\Delta V = \frac{1}{2}\omega B r^2 = 88.5\ mV$. In fact, we were able to generate about a 20 mV potential difference. We understand that the largest reason for the discrepancy is the fact that the field is actually significantly smaller near the center than 0.3 T, and also the field has a fairly large and growing component tangent to the magnet's surface as one goes outward from the center to the edge of the magnet.

Conclusion:

We constructed the rotating assembly for spinning a 6 inch diameter Nd FeB magnet about its magnetic axis in the hope of observing an induced electric field that would suggest the need to interpret the velocity term in the Lorentz force as a relative velocity between charge and magnetic flux. We demonstrated that the electric field sensor borrowed from the University of Michigan should be able to detect the presence of such an induced field, if we had been able to spin the apparatus at the rate we hoped. Unfortunately, certain compromises and features in the design of the case for the magnet meant that it was impossible to balance the entire assembly sufficiently so that the relatively small motor we had purchased could reach its rated maximum speed. The 90 % reduction in speed, coupled with the smaller than expected surface field above the magnet meant that it was impossible for the sensor to detect any small electric field that might have been generated by the rotation of the magnet. We anticipate that a second apparatus built of a stronger and less flexible material, and a stronger motor should be enough to overcome these problems and allow us to measure whether any electric field is induced by the rotation of the magnet. Funding for such an apparatus is currently being pursued.

We would like to thank the National SPS for funding our research!

Respectfully submitted,

James Rabchuk

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3. A.G. Kelly, Phys. Essays 12, 372 (1999)

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