Relativistic Magnetron with a Magnetic Mirror

Stacie Hernandez, BS[1]; Rena Berdine, BS[1]; Artem Kuskov MS[1], Edl SchamilogluPhD[2]
[1]University of New Mexico, [2]Cornell University

SCHOOL OF ENGINEERING

ABSTRACT

The University of New Mexico's Pulsed Power, Beams and Microwaves laboratory has been investigating the research to increase efficiency in a relativistic magnetron for years. In 2002 Dr. Fuks and Dr. Schamiloglu optimized the performance of the Magnetron with Diffraction Output (MDO) with a transparent cathode, achieving an efficiency of 70% in MAGIC simulations. Experiments done at UNM achieved 63% efficiency for the MDO with the transparent cathode. In 2018 Fuks and Schamiloglu proposed and introduced a virtual cathode and a magnetic mirror to the MDO indicating an efficiency of 92% in Particle in Cell (PIC) simulations. Achieving this through experimentation will prove the design of the magnetic mirror and virtual cathode in an MDO efficiency. For this senior design project, we will design the components and power driver circuit that will be used to further experiments towards validating the results from the Fuks and Schamiloglu paper.

ACKNOWLEDGEMENTS

The Magnetic Mirror Team would like to thank the following for the opportunity and assistance:

- Dr. Edl Schamiloglu
- Artem Kuskov
- Pulsed Power, Beams & High-Power Microwaves Student Employees

CONTACT

Artem Kuskov
PPHPM
Email: akuskov@unm.edu
Website: ece.unm.edu

INTRODUCTION

The research in high power microwaves has been one of the emphasis of exploration in the department of defense in our government for the past 50 years. This endeavor has created opportunities to those who seek a deep understanding in this area of the electromagnetic spectrum. The University of New Mexico's school of Electrical and Computer Engineering has been in the efforts to revolutionize the research that has been put forth by distinguished professor Dr. Edl Schamiloglu for more than 30 years.

In our senior design project we will support the High-Power Microwaves Laboratory conduct research in this area by designing the Magnetic Mirror with a virtual cathode inspired by the published report of Dr. Schamiloglu. Dr. Schamiloglu and Dr. Fuks have already published papers that have proven the power efficiency produced by these devices. Where in this project we will try to prove that it can be done through simulations before they are done experimentally.

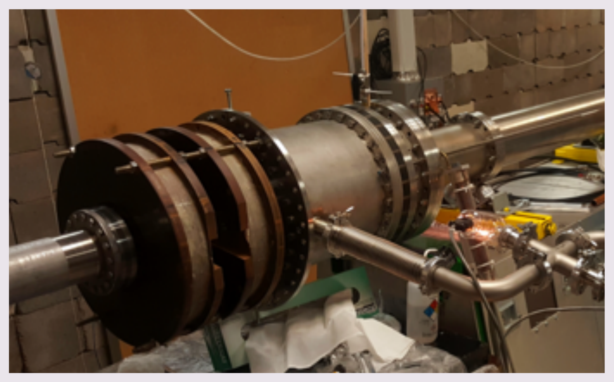

Figure 1. Existing Helmholtz Pair

METHODS AND MATERIALS

The project was defined by three steps. Step one necessitates learning the required software to design and replicate the existing design of the Helmholtz coils and power driver circuit. Step two acts as the research and design phase in which a system effectively generates a magnetic mirror effect (essentially working as an electron trap) through a solenoid and existing Helmholtz pair. The existing power driver also requires modification in order to produce the necessary current to the solenoid. Step three is optional, and would consist of construction, testing, and implementation of the solenoid and power driver circuit designed in step two.

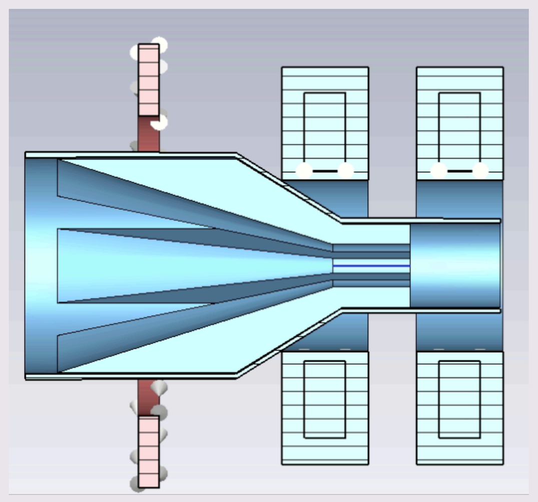

Figure 2. CST Design of Existing Helmholtz Pair with Extra Solenoid

RESULTS

Step 1:
We learned CST and simulated the existing Helmholtz coil pair thereafter. Initially, the magnetic field was not correct due to incorrect boundary conditions set in the simulations.
The uniformity of the field can be verified by measuring the field intensity along the z-axis in the middle of the coils. Results shown in figure 4.
The second part of Step 1 was to simulate the pulsed power driving circuit in LTSpice. The circuit was created by a senior design team in 2013 using TopSPICE, but we had to replicate it using existing software in the lab.
Step 2:
With the available resources, we were able to finalize the physical and electrical coil parameters.
The pulsed power driver model also had to be simplified in order to produce a working output of 300 Amperes.

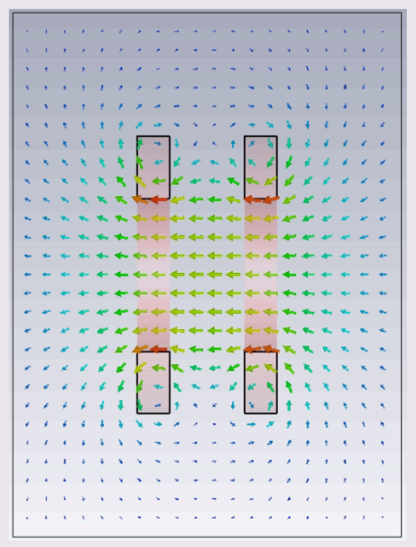

Figure 3. CST Z-Direction B-Field Profile

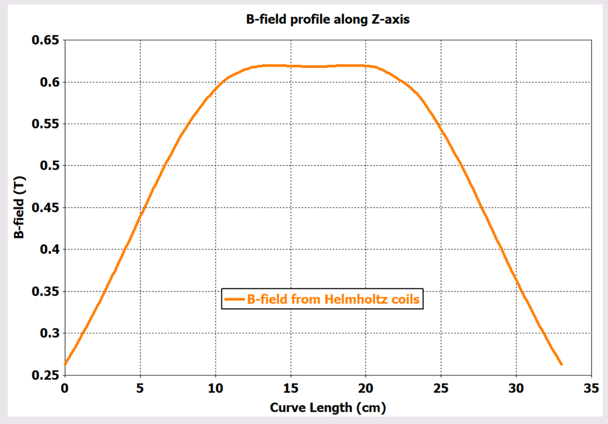

Figure 4. CST B-Field Results

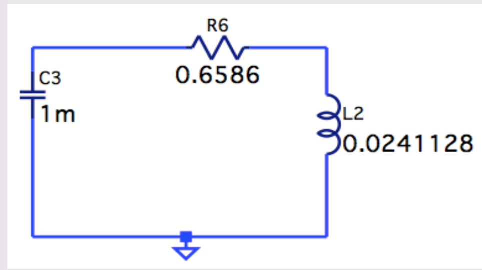

Figure 5. LTSpice Model of Trigger Circuit

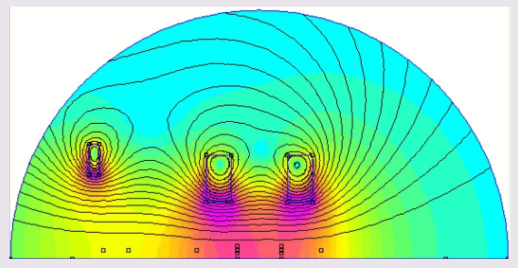

Figure 6. FEMM Results of Density Flux

DISCUSSION

This CST software's limitation prompted us to search for an alternative solution and to verify results in supplemental software. Ultimately, we chose to do this through Finite Element Method Magnetics (FEMM) a 2-D electromagnetic solver. The geometry of the coils is defined such that the cross-section is symmetric around the z-axis and the resultant can be seen in Figure 5 and with the magnetic field profile evaluated. A uniform magnetic field region and an increase in the magnetic field in the magnetic mirror region is clearly visible in these simulations in Figure 6.

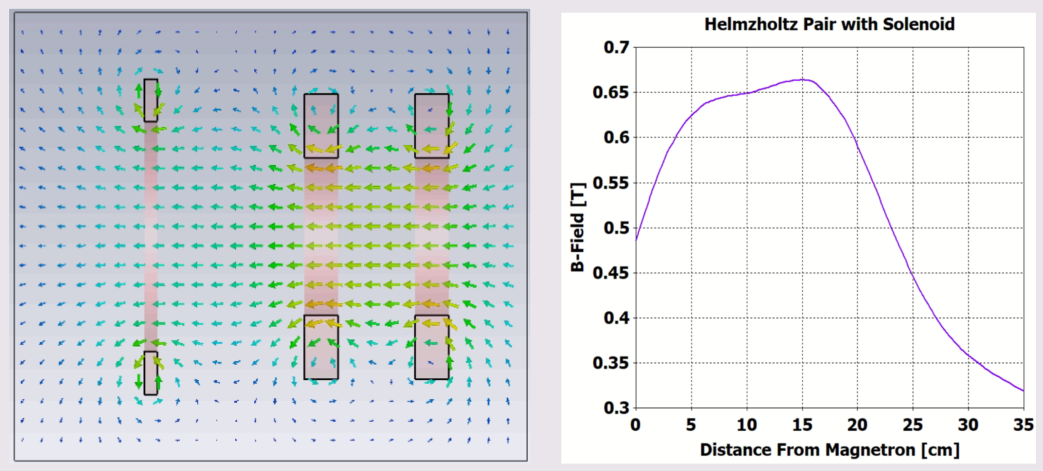

Figure 7. CST B-Field Lines (Left), CST Results of B-Field (Right)

CONCLUSIONS

The first step was successfully completed by modeling the Helmholtz coils and learning CST and LTSpice before moving on to accomplish subsequent goals. In step two, the magnetron's existing Helmholtz coil pair was simulated alongside the solenoid to accurately characterize the magnetic field in the system. The design of the solenoid was critical to implement new parameters for a pulsed power driver to supply a positive half-sinusoid high-energy pulse; however, a simplified version of the circuit was ultimately constructed in order to achieve project goals. Furthermore, a new software, FEMM (Finite Element Method Magnetics) was used to ensure a successful design of the solenoid which confirmed design specifications. The final construction of both the solenoid and pulsed power driver circuit was not achieved as an optional challenge due to extenuating circumstances. To conclude, additional work must be done to demonstrate the magnetic mirror effect in the laboratory.

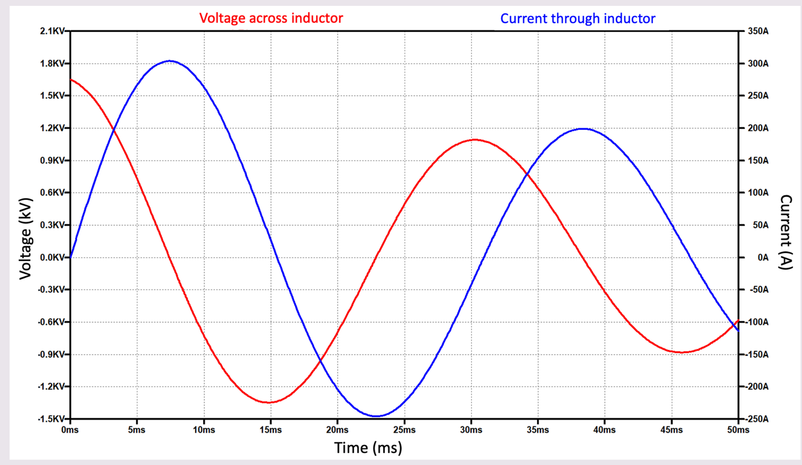

Figure 8. Voltage and Current Amplifier of the simplified Power Circuit

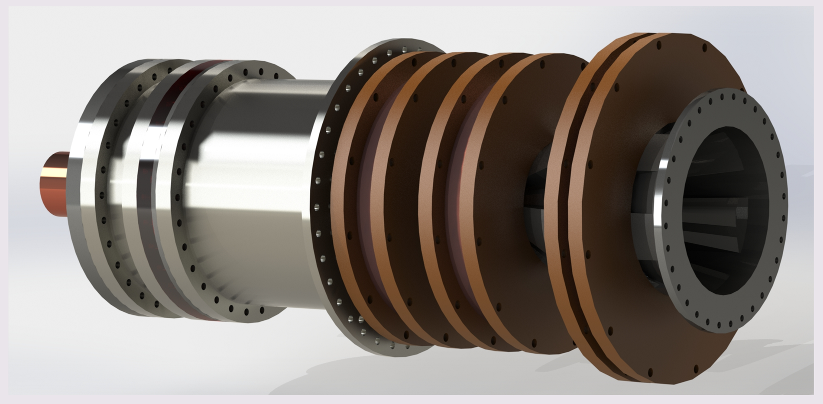

Figure 9. Solidworks whole view of the system

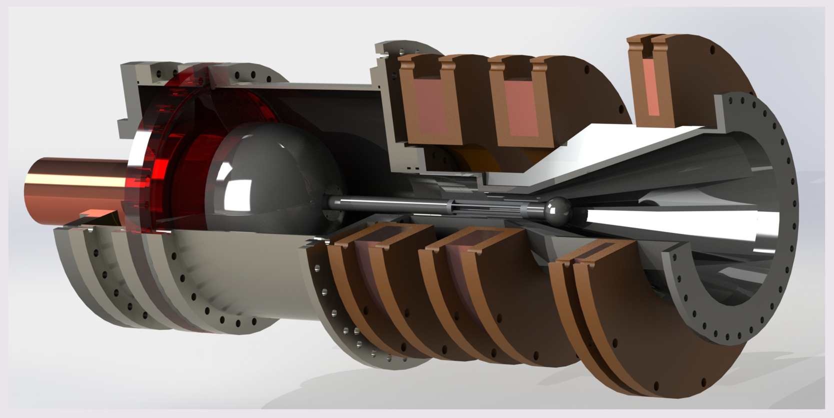

Figure 10. Solidworks ¼ cut view of the new Solenoid added to the system

REFERENCES

1. H. Graf (1961). *Containment in Cusped Plasma Systems* (No. NYO-9496; MF-15). New York Univ., New York. Inst. of Mathematical Sciences.
2. B.W. Bussard and N.A. Krall (1991). *Electron Leakage Through Magnetic Cusps in the Polywell Confinement Geometry*. EMC2-0191-02.
3. J. Lehr and P. Ron (2017) Foundations of Pulsed Power Technology, John Wiley & Sons, New York, NY.
4. W. D. Coles, J. C. Fakan, and J.C. Laurence (1966). *Superconducting Magnetic Bottle for Plasma Physics Experiments* (Vol. 3595). National Aeronautics and Space Administration.
5. J. Benford, J. Swegle, and E. Schamiloglu (2015). *High Power Microwaves, 3rd Ed*. CRC Press, Boca Raton, Fl, p. 462.
6. J. Park, N. A. Krall, P.E. Sieck, D.T. Offermann, M. Skillicorn, A. Sanchez, K. Davis, E. Alderson, and G. Lapenta (2015). "High-Energy Electron Confinement in a Magnetic Cusp Configuration," Phys. Rev. X, vol. 5, p. 021024.
7. M.I. Fuks and E. Schamiloglu (2010). "70% Efficient Relativistic Magnetron with Axial Extraction of Radiation Through Horn Antenna," IEEE Trans. Plasma Sci., vol.38, pp. 1302-1312.
8. M.I. Fuks, E. Schamiloglu, A.A. Koronovskii, and S.A. Kurkin (2017). "Efficient Relativistic Magnetron with Lengthy Virtual Cathode Formed Using the Magnetic Mirror Effect," *Proc. IVEC 2017 (London, UK, April 24-26),* pp.1-2.
9. A.E. Ruark, and M.F. Peters (1926). "Helmholtz Coils for Producing Uniform Magnetic Fields, JOSA, vol. 13, pp. 205-212.
10. CST Studio Suite (2020) (https://www.3ds.com/products-services/simulia/products/cst-studio-suite/).
11. M.H. Rashid and M.H. Rashid (1995). *SPICE for Circuits and Electronics using PSPICE*. Prentice Hall, Upper Saddle River.
12. D. Meeker (2013). "FEMM 4.2 Magnetostatic Tutorial" (http://www.femm.info/wiki/MagneticsTutoria.
13. J. Bernardes, and S. Swindler (2005). "Modeling and Analysis of Thyristor and Diode Reverse Recovery in Railgun Pulsed Power Circuits," *Proc. 2005 IEEE Pulsed Power Conference* (Monterey, CA) pp.79-82.
14. Y. Xu, J. Chen, S. Huang, K. Xu, C. Lu, and P. Li (2020). "Multi-Objective Optimization Design of Repetitive Pulse Magnetic Field System," IEEE Trans. Appl. Supercond., vol. 30, pp. 4901306-1-6.