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Electron Energy Distribution Control

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Overview

The objective of this research is to determine if there is a method to control the electron energy distribution in an electron stream. The control methods must be effective without adding significant amounts of mass to the propulsion system or reducing system lifetimes from their current levels. If such a system can be designed, more efficient electric propulsion systems can be created.

Why Control Electron Energy?

The electron energy is a key part of the ionization of a plasma. Research has shown that the ionization cross-section for neutral-electron collisions is maximized for electron energies two to three times the magnitude of the ionization energy threshold.[2] A more efficient process would only contain electrons that had energies in that regime; this might be accomplished by capturing higher energy electrons and recovering the excess energy to be applied to lower energy electrons.

Theory

This filtering system takes advantage of the varying Larmor radius of an electron based on its energy level. (Eq. 1)

$$r_L = \frac{\bar{v}}{\omega_c} = \frac{\bar{v} \times m_e}{q \times B} \qquad (1)$$

The Larmor radius is determined by the velocity of the electron, which is related to its energy, and the strength of the magnetic field. This relation allows for the filtering of higher energy electrons from lower energy electrons by creating a barrier to the larger path radius of the high energy electrons. This will allow the energy level that is filtered to be adjusted by either replacing the grid screen if a large magnetic field is used, or by increasing or decreasing the B field at lower magnitudes. (Figure 1)

For this high energy filter, it may be possible to design a grid with spacing proportional to the highest energy level that is desired in the output beam. Higher energy electrons would be captured either electrostatically from the charge build up on the grid or due to direct collisions with the grid. Collisional filtering is likely to lead to erosion and electron damage to the screen. This may decrease expected lifetime of a system. As shown in figure 1 below, for the energy regimes of interest the grid spacing will need to be on a very fine scale. The required grids are less than a millimeter, and to differentiate the energy levels, a precision in the micrometer or sub-micrometer scale will be required. By coordinating with the Nano and Micro Devices group, it will be possible to produce the grids on campus.

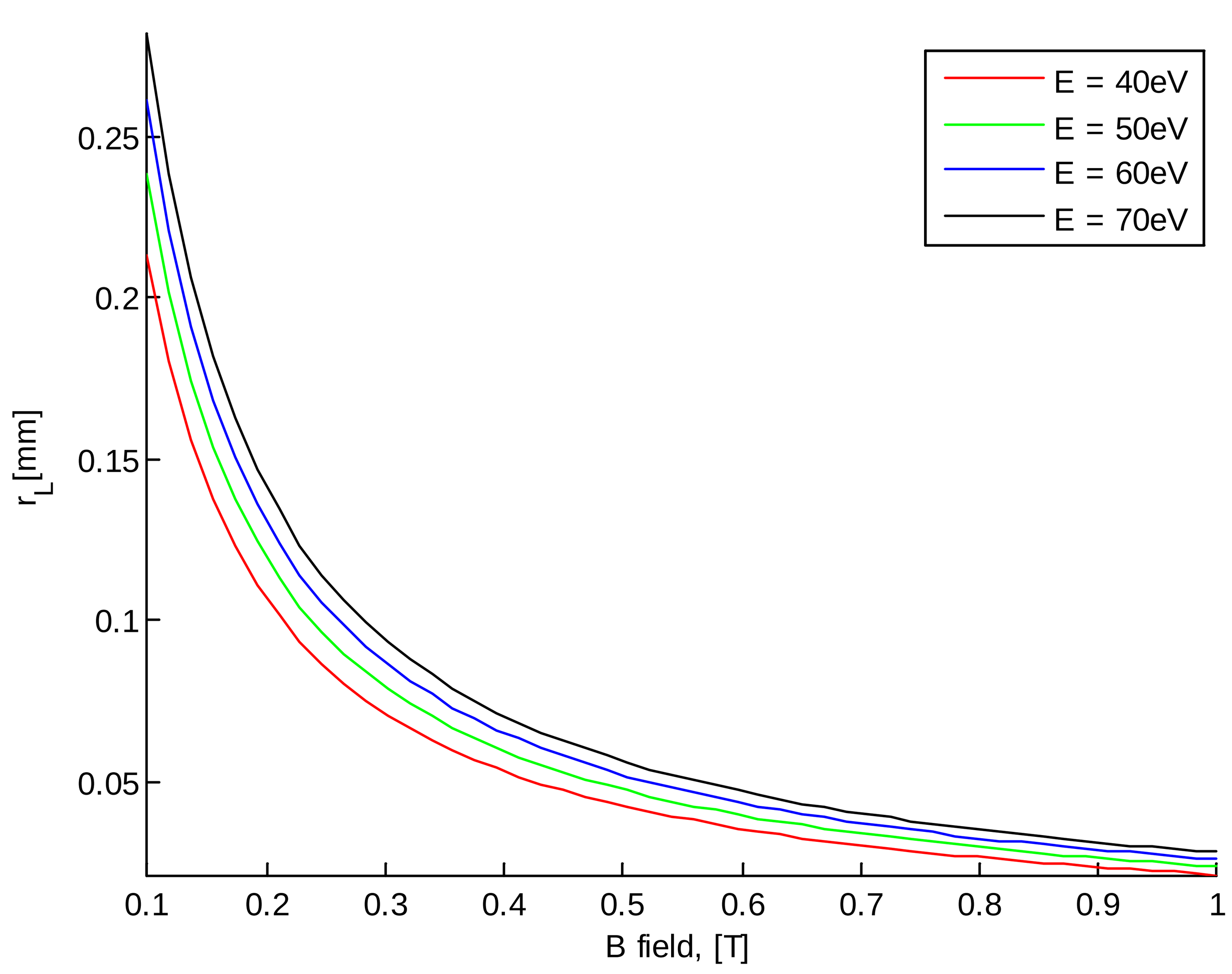

Figure 1: Larmor radius of electrons in a constant B field.

System Design

The system design below would use a electron beam source to test different screen geometries to determine the filtering efficiency and energy levels that are filtered by a given design. (Fig. 2)

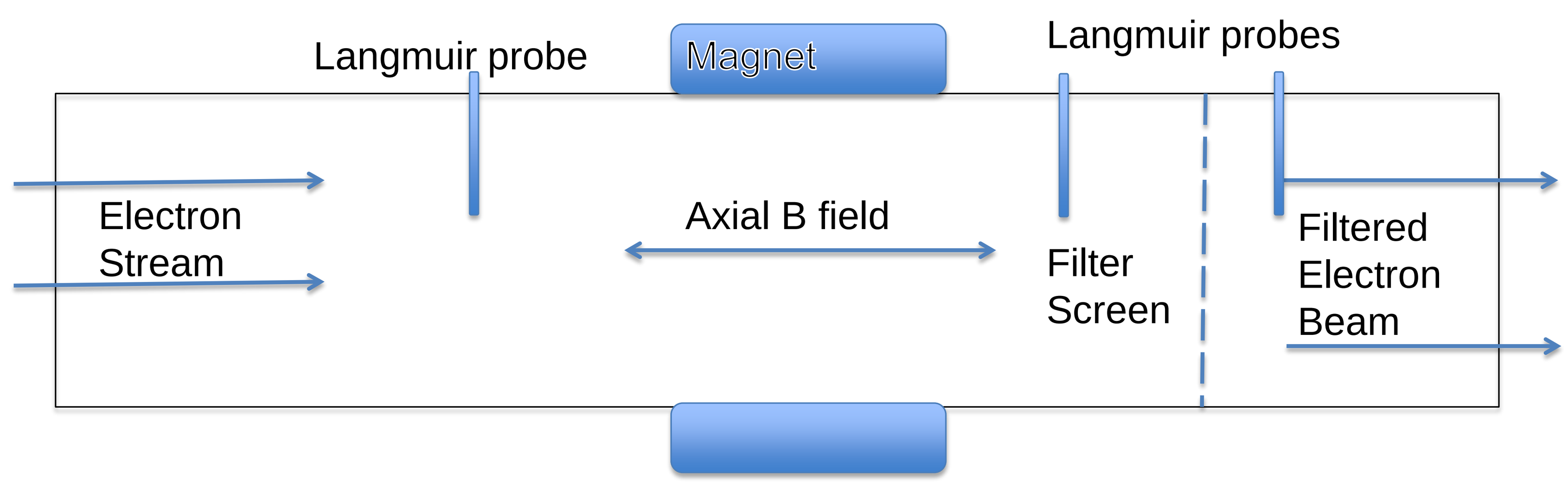

Figure 2: Layout for Electron Beam Filtering Test System

The above test layout will allow for measurement of the electron energy distribution. There will be three Langmuir probes used to collect the data of the distribution prior to the magnetic field, after the magnetic field, and after the filter grid. This will help determine the effects of individual test elements in the experiment and provide additional data to improve grid designs.

The design above may make it possible to use an electron source for multiple gas streams with high efficiency. This design would allow for high efficiency ionization of a gas by matching the electron beam energies to the highest cross-section energy regimes. To change the type of propulsion gas used, only the filter screen would have to be changed to reflect the desired energy level in the electron stream.

Future Work

The next step in this work will be to build or modify a numerical analysis tool to determine if this concept works to filter a majority of the targeted electrons efficiently. This would also be the foundation for designing and numerically testing alternative grid geometries for different energy levels and to determine if there are optimal designs at a given energy level.

If the numerical analysis is successful, a scale test with multiple grids targeting a variety of energy levels will be performed. The data that is collected will be used to validate the numerical results and to improve the numerical system based on the experimental results.

Once both the experimental and numerical systems have been tested and produce valid data, an experimental plan to test alternative screen geometries and a process to rapidly change which screen is in use will be assembled. At the same time, system integration with a plasma system would be analyzed to allow for testing of plasma stream production.

Conclusion

This approach has significant promise in improving propulsion systems. The electron energy distribution in an electron beam may be modified or controlled to produce either a specific profile or to eliminate specific energy levels from the beam. For a low cost, this may provide a way to ionize a particular gas stream efficiently. Additionally, it may be possible to design a system that would be capable of handling multiple propellant gases with the replacement of the filter screen on the electron source.

Acknowledgements

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References

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[2] Fedotov, V. Yu. et al.,"On the electron energy distribution function in a Hall-type thruster," *Physics of* Plasmas, Volume 6, No. 11, 1999, pp.4360-4365