Design of an Arc Chamber for Plasma Impedance Matching

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Abstract

A device for plasma impedance matching is being designed in the Dusty Plasma Laboratory (DPL) at the University of Maryland, Baltimore County (UMBC). The design consists of a high voltage tube modified to allow safe arcing between transmission lines. The distance between wires must be variable to millimeter or better accuracy while maintaining the insulating properties of the high voltage tube. Mechanisms are explored as methods to facilitate the required variable impedance.

Background

Plasma is an ionized gas consisting of ions and free electrons, this arrangement of species provides a medium sensitive to magnetic and electric fields. Dusty plasma is more complex, containing micrometer to nanometer particles immersed within the plasma. These particles (called dust) can accumulate large amounts of charge, allowing them to be influenced by the same fields that make simple plasmas interesting. DPL studies the behavior of dusty plasmas under the influence of strong magnetic fields to advance understanding of plasma physics. Plasma and dusty plasma are relevant to a variety of industries and fields of development including fusion, manufacturing, and medicine. Dusty plasma is a collection of ions, electrons, and neutral particles.

Impedance is the analog of resistance for AC circuits and includes the circuit response to changing current or voltage. Impedance matching is the process of equating impedances, so power doesn't reflect to the source from the load. Plasma generation at DPL is done inductively using an RF source and requires an impedance matching scheme to sustain plasmas. The proposed method of impedance matching is by electrical arcing between transmission lines. A high voltage tube was selected as the core structure to safely contain the electrical arcs. A CAD model was assembled in SolidWorks to model potential designs. The physical tube and CAD assemblies are shown in figures 1 through 3.

Fig 1: High voltage tube

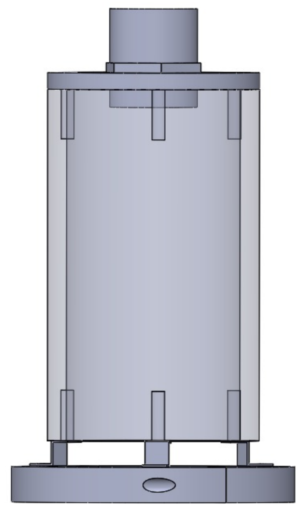

Fig 2: High voltage tube CAD model

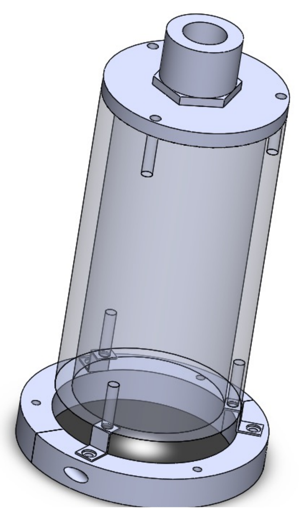

Fig 3: High voltage tube CAD model Iso view

1st Design

Maintaining the insulating properties of the high voltage tube requires the omission of designs which attach directly to the tube itself. Therefore, the first step was to make an insulating plate for the bottom of the high voltage tube as an insulating cover for the arc chamber and a mounting structure. The mechanism then, would consist of an internal mounting structure and gear train. The gear train would function to extend a telescoping arm. A claw was fixed to the end of the telescoping arm.

Extension and retraction of the arm varies the arc gap between the wires providing the required range of impedances. The wires extend along the neutral axis of the tube and were to be actuated by an external dial. This design, shown in figures 4 and 5 was rejected due to complexity, space and expense concerns.

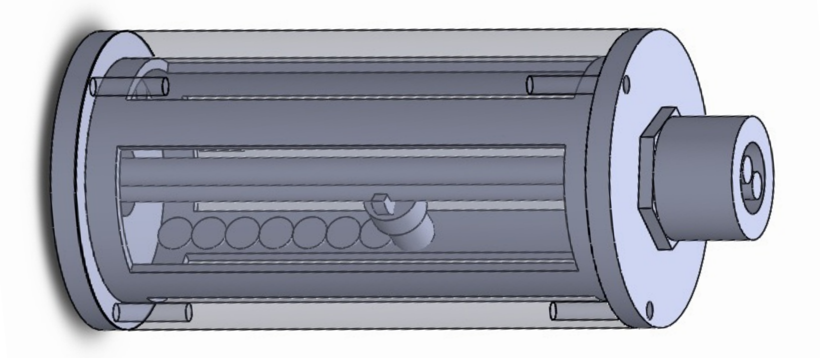

Fig 4: Arc tube 1st design telescoping structure and mechanism

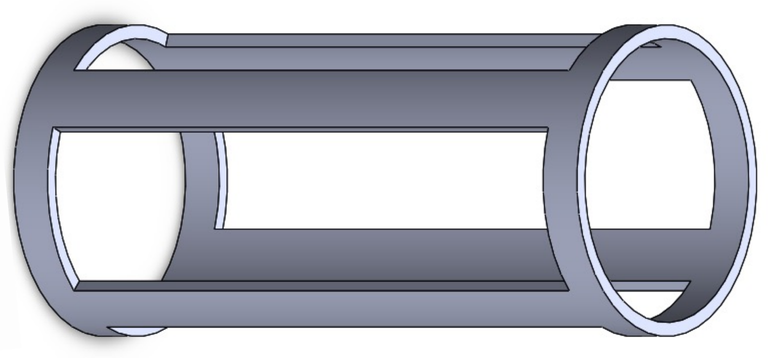

Fig 5: Arc tube 1st design armature mounting structure

Second Design

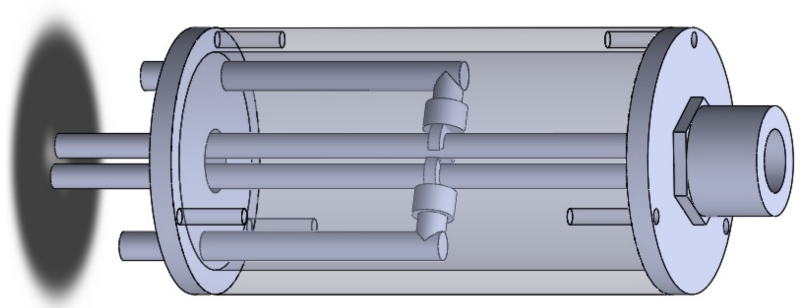

Fig 7: Arc tube 2nd design

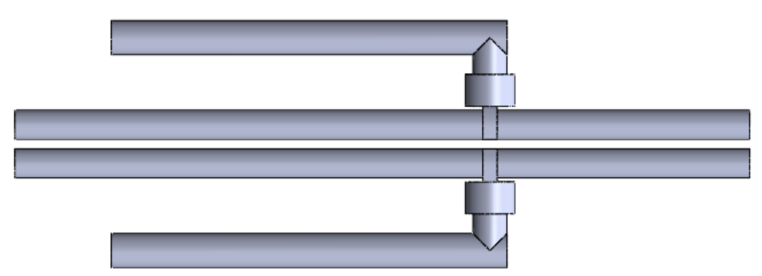

Fig 8: Arc tube 2nd design armature only

Was less complex than the previous iteration. In this design gear trains were replaced by two rotatable arms connected and moved by a timing belt. One shaft functions as a knob for manual actuation of the system and includes a gear connected to its base. The gear, along with a locking pin, would aid in moving between several discrete distances which the armature (could repeatably achieve). Gear selection attempted to maximize of the number of teeth while maintaining a gear diameter less than that of the high voltage tube. With the restriction on the gear diameter and the need to quickly source materials a suitable gear was apparent. A gear with 64 teeth was selected. To determine whether this number of teeth fit the required accuracy, the position of the arm at each rotational point would need to be calculated using the following equation.

$$x = r * \cos(\theta)$$

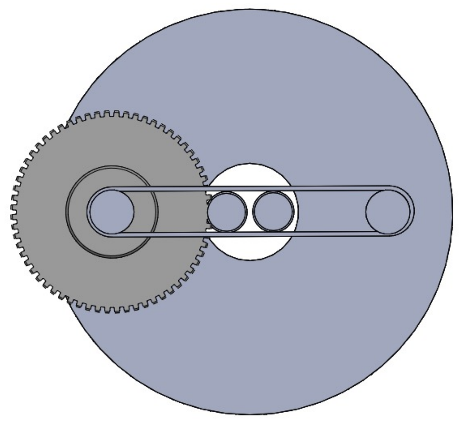

Fig 9: Arc tube 2nd iteration gear mechanism

To use the above equation, the total angle that the armature could rotate and the angle between each gear tooth was needed. The angle between teeth was a simple matter of dividing the total number of teeth by 360 degrees. The result was an angular distance of 5.625 degrees between each tooth. The determination of the total angle which the system could rotate required more steps.

The rotating arm in its initial and final positions created triangle a which, given knowledge of the tube radius, length of the arm and the center of rotation for the arm, allowed the law of cosines to be to solve for θ.

$$c^2 = a^2 + b^2 - 2ab * \cos(\theta)$$

With a tube radius of 28.575mm, an arm length set to 18.4mm and the arm centered 23.876mm away from the center of the tube the total angle was found to be 84.0 degrees. Using the radius above and 15 points spaced 5.625 degrees apart the Figure 10 was constructed. From this scatterplot the distance between the final two points was 2.77mm.

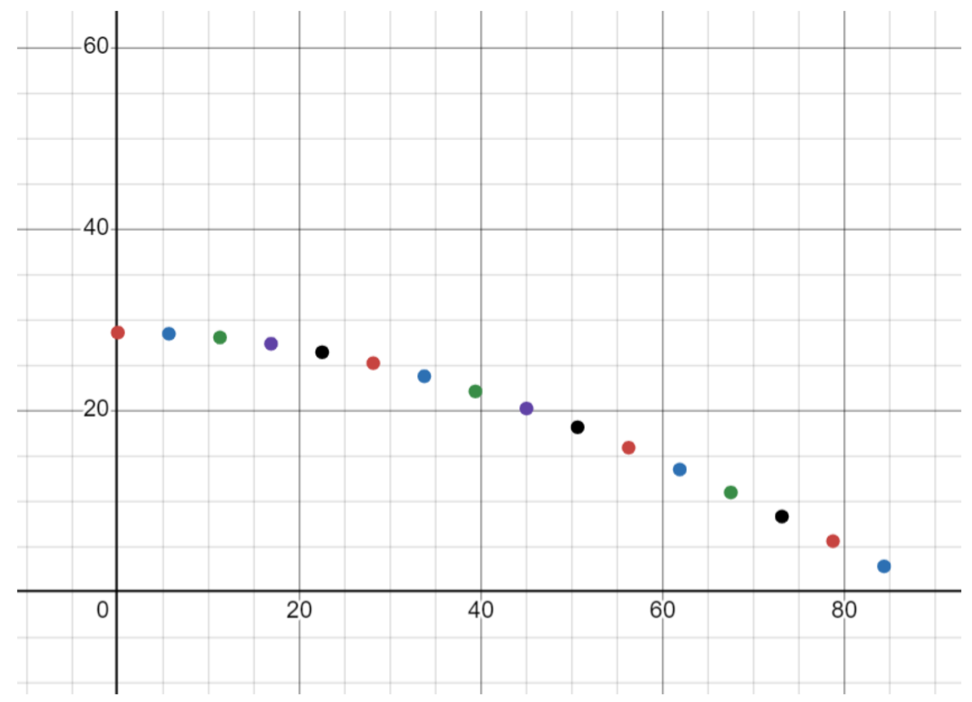

Fig 10: Arm to center distance as a function of θ

This design was an improvement in terms of space used and complexity, however, the readily available gears did not provide a small enough step size to allow the required precision.

Future Work

The mechanisms considered here were not able to meet the requirements for the for the arc tube to function as a viable means of plasma impedance matching for DPL. Despite this there are more designs which will be explored to facilitate safe arcing. Placing a mechanism thought the tube as shown in figure 11 or attempting to move the wires using a mechanism located farther from the arcing point will be considered to achieve a suitable design.

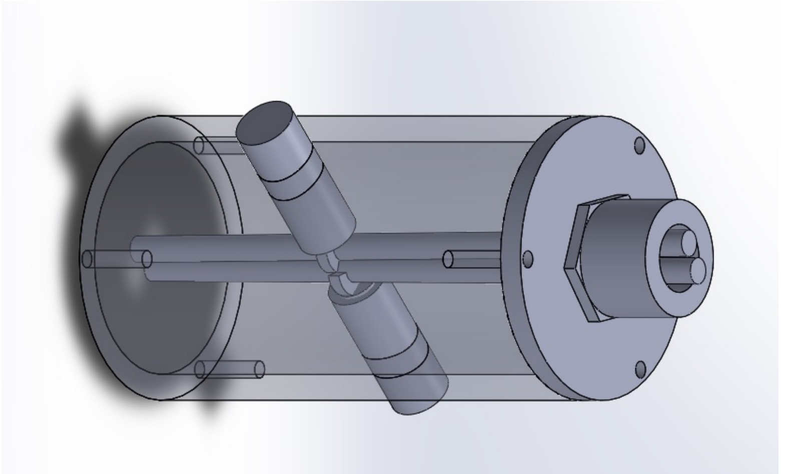

Fig 11: Arc tube future concept

Acknowledgements

Maryland Space Grant Consortium