Numerical Investigation of Plasma Flows in Magnetic Nozzles

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Magnetic nozzles are used in many laboratory experiments in which plasma flows are to be confined, cooled, accelerated, or directed. At present, however, there is no generally accepted theoretical description that explains the phenomena of plasma expansion in and detachment from an externally-imposed magnetic field. The latter is an especially important problem in the field of plasma propulsion, where the ionized gas must detach from the applied, solenoidal magnetic field to realize thrust production. In this paper we simulate a plasma flowing in the presence of an applied magnetic field using a multidimensional numerical simulation tool that includes theoretical models of the various dispersive and dissipative processes present in the plasma. This is an extension of the simulation tool employed in previous work by Sankaran et al. [1–3] The new tool employs the same formulation of the governing equation set, but retains the axial and radial components of magnetic field and the azimuthal component of velocity that were neglected in Refs. [1–3]. We aim to compare the computational results with the various proposed magnetic nozzle detachment theories to develop an understanding of the physical mechanisms that cause detachment. An applied magnetic field topology is obtained using a magnetostatic field solver (see Fig. 1), and this field is superimposed on the time-dependent magnetic field induced in the plasma to provide a self-consistent field description. The applied magnetic field and model geometry match those found in experiments by Kuriki and Okada. [4] A schematic showing the setup used in those experiments is shown in Fig. 2. We model this geometry because there is a substantial amount of experimental data that can be compared to our computations, allowing for validation of the model. In addition, comparison of the simulation results with the experimentally obtained plasma parameters will provide insight into the mechanisms that lead to plasma detachment, revealing how they scale with different input parameters.

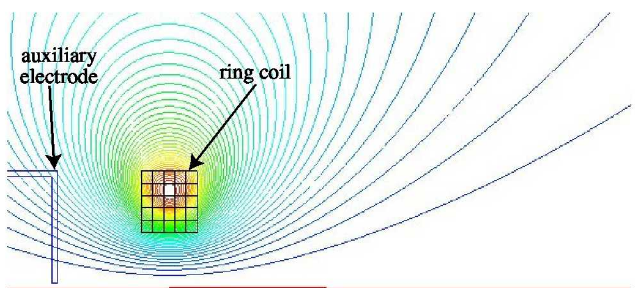

Figure 1. Magnetostatic simulation of flux lines in the $r-z$ plane of the nozzle in Ref. [4].

References

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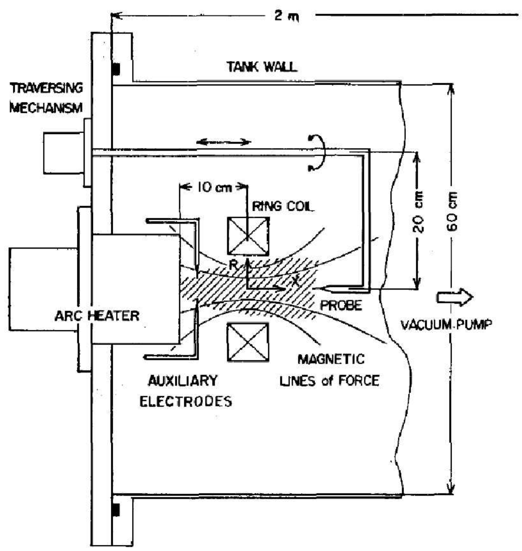

Figure 2. Schematic illustration of the magnetic nozzle experiment used by Kuriki and Okada (from Ref. [4]).