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Improving spheromak helicity injection by eliminating the constraint imposed by Paschen breakdown physics

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Spheromaks are based on helicity injection, i.e., increasing the amount of flux linkage. Helicity injection involves injecting new magnetic flux that links pre-existing flux. The standard example is a coaxial magnetized plasma gun where new toroidal magnetic flux links pre-existing poloidal flux produced by external coils. Because plasma is frozen to magnetic flux, toroidal flux injection necessarily involves an associated injection of plasma. The Caltech spheromak formation experiment has shown very clearly (via high speed imaging, HeNe density interferometry, Stark broadening to measure density, Doppler broadening to measure velocity, and magnetic probes) that this injected plasma is in the form of a highly collimated fast jet that is coaxial with the electrodes. The particle source for this jet is dense plasma at nozzles located in the gun electrodes. This dense plasma results from the ionization of neutral gas injected into the nozzles by fast gas puff valves. The gas valves have been adjusted to provide a neutral density that is optimum for Paschen breakdown along the poloidal magnetic field lines linking the cathode and anode electrodes.

The density of the plasma in the nozzles and hence the density of the jet plasma is thus indirectly governed by Paschen breakdown physics. This has the unfortunate consequence that the jet plasma density is much higher than is desirable for obtaining a hot, fusion-relevant spheromak plasma (the spheromak plasma results from kink instability of the jet plasma). The neutral gas pressure before breakdown has to be adjusted to be in a range consistent with Paschen breakdown, but this range is such that there is excessive plasma density at the nozzles after breakdown has been achieved. While the situation is better than a static pre-fill where the entire chamber volume has an excessively high gas pressure, it nevertheless results in plasmas that are too dense and too cold for fusion purposes.

A way out of this dilemma would be to eliminate the limitations imposed by Paschen breakdown physics. This would enable operation at much lower densities so that the same input energy would be shared by a smaller number of particles that would then be hotter. This smaller number of particles would contain the same magnetic flux so the helicity injection would remain the same.

It should in principle be possible to eliminate the constraint imposed by Paschen breakdown by pre-ionizing the gas in the nozzles. Possible methods include electron cyclotron resonance, helicon waves, thermionic emission, or UV light. It is not obvious at present which of these methods would be optimum and so it is important to consider all of them. If any of these methods enables removing the constraint imposed by Paschen breakdown, new and much improved spheromak operational regimes will result.