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Inflation of dipole field in laboratory experiments for simulation of Hot Jupiter magnetosphere

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Abstract

We describe experiments on a novel type of magnetospheric interaction. A localized source produces plasma which expands outward from surface of the dipole and inflates magnetic field. Such scenario can be applied to weakly magnetized Hot Jupiter at close orbit. Intense erosion and evaporation of atmosphere and subsequent gas ionization by EUV radiation may produce sufficiently strong plasma outflow to influence overall particle loss balance and magnetopause stand off distance [1].

1. Experimental set up and results

In laboratory experiment symmetrical plasma outflow was generated by discharge along cable surface. Injector design is shown in fig. 1. Two such injectors are fasten to a cylindrical casing with size ∅9×7 cm inside of which a pulsed magnetic dipole with moment up to $M_D=3\cdot10^5$ G·cm^3 is placed as shown in fig. 2. Diagnostics consisted of Langmuire probes, Faraday cap, Rogovski coil and magnetic probes.

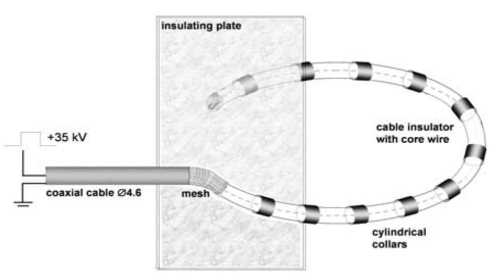

Figure 1: Sketch of plasma injector made of a coaxial cable.

Discharge consists of damped oscillations, and first four half-cycles produce sequential plasma flows. Repetitive flows overlap sufficiently well to constitute a continues flux. At the time when the fourth half-cycle starts to generate plasma, the plasma produced by the first half-cycle reaches distance of about 40 cm which is much larger than the injector size. Interaction of expanding plasma with dipole field is determined by Alfven-Mach number. From measured ion current and given dipole field it was calculated that a critical value MA=1 is reached at a distance of about 15 cm. In fig. 2 profile of total magnetic field which is a sum of variation generated by plasma in dipole field and the dipole field itself is shown. One can see that at R<20 cm expanding plasma decreases dipole field, while at R>20 cm increases it. Moreover, at R>25 cm generated field is much larger than the initial dipole one and is still increasing at the end of the measurement range.

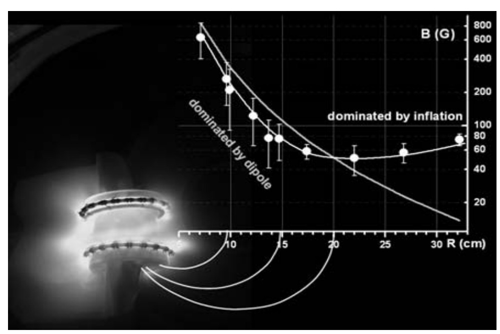

Figure 2: Picture of coil injectors put over dipole casing. Also shown is profile of total magnetic field (○) measured in equatorial plane and initial dipole field (gray).

To measure current in plasma Rogovski coil with diameter 4 cm was employed. It appears that current is strongly localized around equatorial plane having width of about ΔZ=6 cm at R=20 cm as demonstrated in fig. 3.

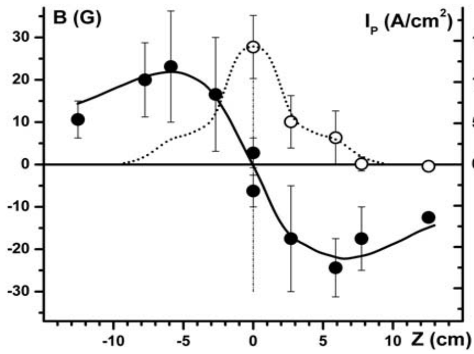

Figure 3: Profiles of radial component of magnetic field δB_r (●) and J_φ component of current in plasma (○) across the equatorial plane at a radial distance of R≈20 cm.

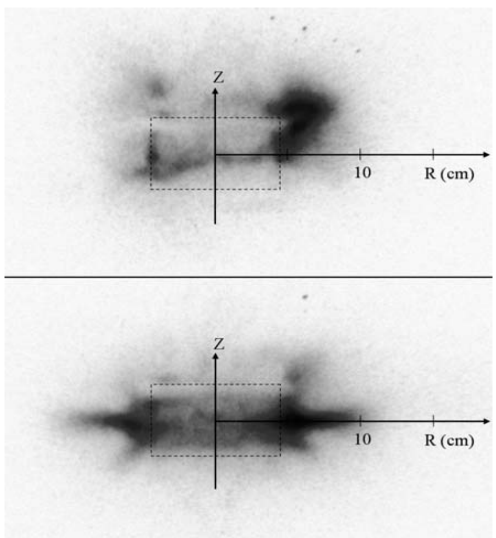

Figure 4: Snap-shot images of plasma expanding in free space (upper panel) and in dipole magnetic field (bottom).

The δB_r component shows typical reversible structure. The sign corresponds to stretching of dipole field lines. Comparison of short-time images of plasma expanding in a free space and in dipole magnetic field also reveals formation of a thin disk-like structure (fig. 4).

2. Summary and Conclusions

Current generated due to inflation is such that the Lorentz force decelerates radial expansion of plasma. Estimation of initial kinetic energy and of the change of magnetic energy in the system based on the measured data yields E_k≈0.38 J and E_b≈0.26 J. Thus, observed inflation of magnetic field is consistent with available energy of plasma flow. Additional magnetic moment generated by inflation is estimated to be 2-3 times larger than the initial dipole one due to extended distribution of current. Thus, in case of interaction with external plasma flow like a Stellar Wind, a stand of distance should be determined by inflated field.

Obtained results demonstrate laboratory model of magnetodisk created by inflation. This process might be an important factor in formation of Hot Jupiter magnetosphere [2]. In future experiments interaction of Stellar Wind with inflated magnetic field is planned to be studied.

Acknowledgement

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