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Investigation of Region-1 field aligned current of planetary magnetospheres in laboratory experiments

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Abstract

In experiments on magnetic dipole interacting with laser-produced plasma a generation of intense Field Aligned Current (FAC) system was observed for the first time in a laboratory. Detailed measurements of total value and local current density, of magnetic field at the poles and in the equatorial magnetopause, and particular features of electron motion in the current channels revealed its similarity to the Region-1 current system in the Earth magnetosphere. In laboratory new and otherwise unavailable details have been obtained such as dependence on the dipole moment and inter-relation with electric potential at the plasma-field boundary layer.

1. Introduction

FAC is a key element in the Earth magnetosphere - ionosphere coupling. Magnetospheric currents can flow into ionosphere along field lines and closure transverse to magnetic field due to finite Pedersen conductance. Region-1 current at the dayside maps in the Plasma Sheet Boundary Layer and is a direct result of the Solar Wind interaction with the Earth magnetic field. Dependence of magnetosphere-ionosphere coupling on IMF is attributed to reconnection at the dayside magnetopause. Existing models explain saturation of transpolar potential by a feedback influence of FAC on plasma motion and magnetic field near the magnetopause. During the last two decades a number of investigations based on MHD numerical simulation were performed, such as on influence of ionosphere conductance on the properties of SW interaction with magnetosphere, impact of energetic CME plasma on the Earth magnetosphere and ionosphere and others. In most MHD simulations that take into account ionospheric conductance a generation of Region-1 current was observed as well as its significant increase following dynamic pressure jumps in SW.

Discovery in 1974 of intrinsic magnetic moment of the Mercury by Mariner opened up new possibilities in the physics of planetary magnetospheres. From spacecraft measurements a presence of FACs on the nightside was deduced, and the inferred current turned to be unexpectedly large and comparable to that of the Earth, ~ 1 MA. In view of soon to be operating MESSENGER and planned BepiColombo missions, the influence of FACs on structure and dynamics of magnetosphere was formulated as one of the main problems in Mercury investigations [1]. Due to relatively small size and large gyroradius of exsosphere ions laboratory simulation of Hermean magnetosphere looks promising. In the present work FACs are investigated in experiments conducted at KI-1 Facility [3, 4].

2. Experimental results

In laboratory simulation we use energetic laser-produced plasma and quasi-stationary theta-pinch plasma overflowing magnetic dipole with moment up to 10^7 G·cm^3. In a typical set up two laser beams with energy ~200 J are focused on a solid target placed at a distance of 60 cm from the dipole. Generated plasma expands towards the dipole in a cone ~1 sr with velocity ~150 km/s and in the interaction region has ion density up to 10^{13} cm^{-3}. Characteristic magnetic Reynolds and Knudsen numbers are about 5. Typical stand off distance 10-25 cm is about three times larger than ion gyroradius. Diagnostics consists of electric and three component magnetic probes and short time imaging. Transpolar current and transpolar potential were measured by device shown in the figure. Poles are covered with metallic plates electrically detached from the dipole cover and separated from each other along the interaction axis.

A shortcutting shunt measures total current flowing between plates.

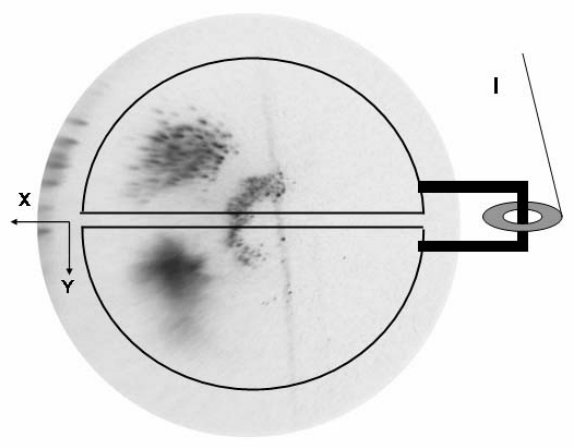

Figure 1: Snapshot of the dipole polar region. Also shown is a scheme of transpolar current measurement.

It was found out that besides Chapman-Ferraro currents which shield dipole a double FAC system is generated. Local current density in plasma was measured by Rogovski coil while total FAC value was obtained directly as a cross-polar current between plates simulating ionosphere. In particular, FAC is directed in a sense of Region-1 system and closes via conductive dipole cover. In case of dielectric cover it doesn't exist. Total FAC value is comparable to total Chapman-Ferraro current. Comparison of results with conductive and non-conductive covers of dipole revealed that FAC significantly changes magnetospheric field in the equator plane as well at poles. Because of small size Hermean magnetosphere might be especially sensitive to FACs. Scaling shows that corresponding current of ~1 MA might contribute as much as several percents to the main dipole field of Mercury.

It was proposed as early as in [2] that a source of dayside FACs is in the low-latitude boundary layer (LLBL) where transfer of plasma, momentum and energy from the magnetosheath to the magnetosphere takes place. Viscous interaction due to particle scattering and waves transports SW momentum across the magnetopause. Thus, plasma in a thin boundary layer on each flank moves antisunward and stretches frozen magnetic field lines. On the inner side of the layer tangential drag and stress are mapped to the ionosphere along closed field lines establishing convection pattern. Due to highly different conditions and collisions the stress is loaded on ionosphere generating electric field and net cross-polar current. In laboratory magnetosphere this scenario was verified by experimental evidence of a direct link between FAC and electric potential generated by plasma in LLBL. Measurements on the flanks of magnetosphere revealed that there exists convection electric field generated by cross-field plasma motion and a global dawn-dusk potential. The plasma potential drop between dawn and dusk flanks corresponds by value to transpolar potential independently measured at dipole poles. Moreover, a feedback influence was observed as the electric potential in LLBL was reduced in case of strong FACs. Magnetic perturbation generated by FAC in LLBL has been measured. By comparing probe signals between the cases of conductive and non-conductive dipole covers the existence of tangential component of magnetic field was found out. This specific field has quadruple symmetry and changes sign at crossing meridian or equatorial plane. It was interpreted as sheared stress of main dipole field generated in the LLBL by plasma drag.

Acknowledgements

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