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Region-1 field aligned currents in experiments on laser-produced plasma interacting with magnetic dipole

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Abstract. In previous experiments by the authors a generation of intense field aligned current (FAC) system on Terrella poles was observed. In the present report a question of these currents origin in a low latitude boundary layer of magnetosphere is investigated. Experimental evidence of such a link was obtained by measurements of magnetic field generated by tangential sheared drag. Results suggest that compressional and Alfven waves are responsible for FAC generation. The study is most relevant to FAC generation in the Earth and Hermean magnetospheres following pressure jumps in Solar Wind.

Keywords. Magnetosphere, field aligned current, low latitude boundary layer.

1. Introduction

Field-aligned currents play an important role in the magnetosphere-ionosphere coupling. It was proposed as early as in Eastman (1976) that a source of dayside Region-1 FAC is in the low-latitude boundary layer (LLBL) where transfer of plasma, momentum and energy from the magnetosheath to the magnetosphere takes place. Plasma in a thin layer on each flank moves antisunward and stretches frozen magnetic field lines. On the inner side of the layer tangential stress is mapped along closed field lines establishing convection pattern. The stress is loaded on ionosphere generating electric field and net cross-polar current. This dawn-dusk Region-1 current drags ions antisunward over poles and decelerates tangential plasma motion in LLBL far from the Earth.

There is a body of observational data on FACs at high latitudes, but so far nothing is known about related features in a driver region. While only *in sutu* observations can unequivocally link ionospheric FACs with LLBL, in this work we present exactly such evidence obtained in laboratory experiment. As described in the previous paper by Shaikhislamov *et al.* (2009), laser-produced plasma interacting with magnetic dipole, besides forming a well defined dayside magnetosphere, generates intense field aligned current system. Detailed measurements of total value and local current density, of magnetic field in equatorial and polar region revealed its similarity to the Region-1 system in the Earth. Such currents were found to exist only if they can closure via conductive cover of the dipole. Comparison of conductive and dielectric cases revealed specific magnetic features produced by FAC and their connection with electric potential generated in the LLBL. The next natural step is to look in the LLBL for a specific magnetic feature associated with FAC, namely for a tangential magnetic field produced by sheared plasma motion. Measurements presented in this paper reveal that such a field is indeed present.

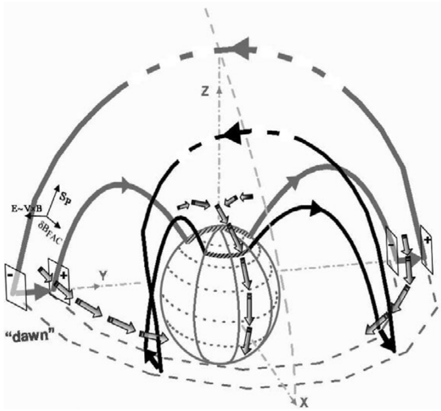

Figure 1. A scheme of magnetosfperic generator. On the flanks of LLBL plasma moves along the boundary across field and with shear along magnetic field. This generates electric field and azimuthal component of magnetic field δB_{FAC} such that the Pointing vector S_p is directed upward. Sequential arrows show that azimuthal field is positive at the dawnside and negative at the duskside. Magnetic field produced by FAC loops inside magnetosphere is sunward over the North pole and opposite to the dipole field at the equator.

It has specific spatial structure with maximum inside magnetosphere and immediately adjacent to LLBL.

2. Experimental results and conclusions

Fig. 1 demonstrates schematically magnetospheric generator driving Region-1 FAC in the Northern hemisphere. By thick lines two current loops are drawn, in the terminator plane and topologically similar at the dayside. Both loops closure through the ionosphere.

Experiment has been carried out at KI-1 space simulation Facility, which includes vacuum chamber $\varnothing 1.2 \times 5\ m$. Two CO_2 laser beams of 70 ns duration and 150 J of energy each were focused and overlapped into a spot 1 cm in diameter on surface of a solid target. Plasma expanded inertially in a cone $\approx 1\ sr$ with an average velocity $V \approx 1.5 \cdot 10^7\ cm/sec$. A total kinetic energy and a number of ions in the plasma was $\approx 40\ J$ and $\approx 5 \cdot 10^{17}$ respectively. At the axis of plasma expansion at a distance of 60 cm magnetic dipole with moment $\mu = 1.15 \cdot 10^6\ G \cdot cm^3$ was placed. The dipole has a spherical stainless cover shield 8 cm in radius. The surface could be made un-conductive by placing over a thin dielectric film. At a time of about $t = 2\ \mu s$ after laser irradiation a well defined magnetopause is formed at a distance of about $R_m = 15\ cm$. Due to specifically adjusted pulse and tail generation mode of laser oscillator, main plasma flow is followed by a second pressure jump. It slightly compresses magnetosphere and causes pronounced response in FAC. Such conditions resemble a pressure jump in the SW.

By measuring magnetic field above the equator plane ($Z = 4\ cm$) and off the meridian plane at the afternoon and postnoon sections for North and South orientation of dipole moment it was found that the azimuthal component of magnetic field has quadruple structure that corresponds to Fig. 1. It changes sign at crossing either meridian or equator plane. Most importantly, the structure of the azimuthal field was different for conductive and dielectric dipole covers, that is in dependence on FAC system being present or not. The essence of the difference is revealed in spatial profiles given in Fig. 2 for a number of sequential times marked in μs. From the main δB_Θ component of magnetic field perturbation (upper panels) one can see how the plasma forms magnetosphere and

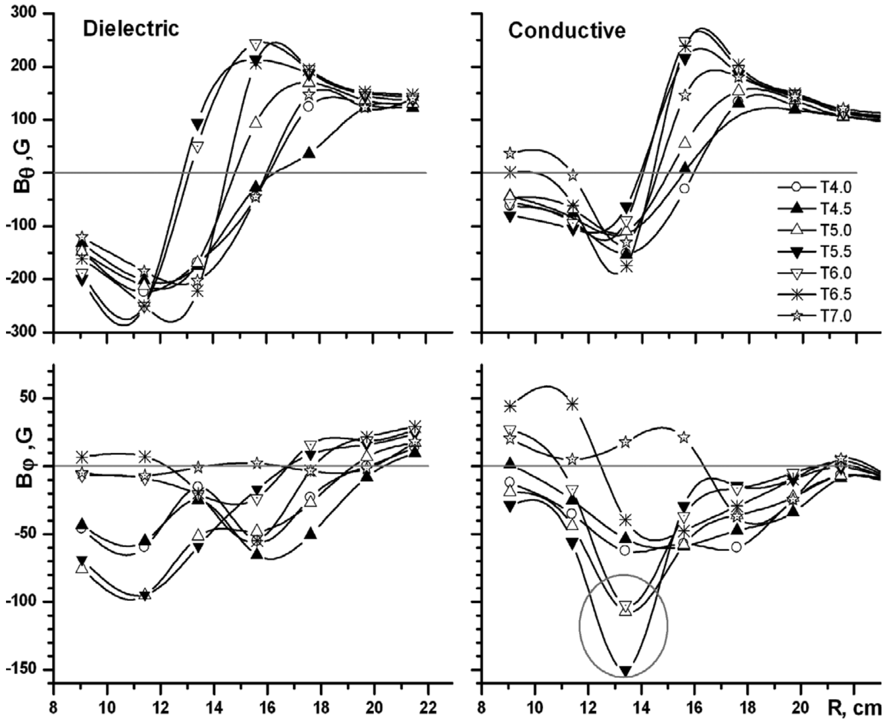

Figure 2. Spatial profiles of δB_Θ and δB_φ components at the duskside at different times for cases of dielectric and conductive dipole cover.

how the second pressure jump pushes it slightly closer to dipole. The boundary layer (from signal minimum to maximum) is about $3 \div 4$ *cm* wide. Field compression inside magnetosphere is substantially reduced for the conductive case. The second pressure jump makes the field even smaller than initial dipole one. This is interpreted as equatorial depression caused by Region-1 FAC as shown in Fig. 1. The azimuthal component δB_φ is presented in the lower panels of Fig. 2. For the dielectric case it shows oscillations and general increase by amplitude towards dipole. For the conductive case however, there is a much more pronounced structure – a compact minimum inside magnetosphere but immediately adjacent to the boundary layer (marked by the circle). It is formed solely by the second pressure jump.

Spatial structure of azimuthal field suggests current which flows downwards on the inner side of LLBL (for dusk sector). Total downward current can be estimated as $1.5 \div 2.5$ kA which is close to total cross-polar current measured independently by method described in Shaikhislamov *et al.* (2009). Thus, experiment provided three facts: The field corresponding to expected sheared stress in LLBL is indeed generated. Field-aligned current associated with it quantitatively agrees with independently measured total cross-polar current. Third, when ,,ionosphere" is non-conductive azimuthal field is also different and doesn't have well defined region of local maximums. Correlation analysis of magnetic probe signals shows that maximum of azimuthal component moves ahead and synchronously with magnetopause current. This indicates that compressional motion of boundary layer drives shear Alfven waves which carry FAC to the ionosphere. Such model aimed to explain observed transient geomagnetic variation was proposed by Glassmeier *et al.* (1992).

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References

Eastman, T. E. 1976, *Geophys. Res. Lett.*, 3(11), 685

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Glassmeier, K. H. & Heppner, C. 1992, *Geophys. Res.*, 97(A4), 3977

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