A statistical survey of the magnetotail current sheet

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Abstract

Using Cluster magnetometer data during summer 2001 and 2002, when the spacecraft traversed the magnetotail, we have performed a survey of current sheet and its current. We applied a superposed epoch analysis to simple, monotonous current sheet crossings and obtained a statistical profile of the current sheet. We find that the averaged structure of the current sheet fits well with the Harris current sheet description. By using the four spacecraft measurements, the current is calculated and a statistical current density profile of the current sheet is produced.

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1. Introduction

The magnetotail current sheet has long been recognized as a site of important plasma dynamics. The current sheet is a relatively narrow region within the plasma sheet, which separates the magnetotail into two adjacent hemispheres with opposite magnetic field polarities. The current sheet structure is often approximated by a Harris-type current sheet solution (Harris, 1962), i.e., with maximum dawn-dusk current intensity at the center of the sheet.

From the earliest observations, it has been found that the current sheet appears to be in motion relative to spacecraft due to the solar wind condition and geomagnetic activity (Speiser and Ness, 1967). Crossings of the current sheet by spacecraft have been used to study its current structure (McComas et al., 1986). In this paper we statistically study the structure of the current sheet observed by the Cluster spacecraft. Compared to the earlier statistics using ISEE 1 and 2, or GEOTAIL, one of the major differences of using Cluster data is that we are able to use the four spacecraft to calculate the current directly.

2. Selection of cases

The primary data used in this study are the Cluster magnetic field data (Balogh et al., 2001). We identify the current sheet crossings by \( B_x = 0 \) and the magnetic field intensity reaches a minimum. We chose to use 12-min intervals with the current sheet crossing in middle of these intervals. The field data are in geocentric solar magnetospheric (GSM) coordinates. At the time of \( B_x = 0 \), there is a dip in field strength. Further, the field strength should be less than 10 nT at \( B_x = 0 \). No multiple crossings of the current sheet are allowed for the first and the last 3 min of the 12 min data sequence, to exclude cases when the s/c stays near the current sheet for the entire 12 min. We note that this condition differs from an earlier study of current sheet waves by Volwerk et al. (2003) in which they have selected 12 min intervals when the spacecraft are in or near the...
current sheet. The reason behind this 12 min choice was that the characteristic current sheet travel distance for 12 min is of the order of 1–2 Re, roughly equal to the thickness of the current sheet when no thinning process exists (Baumjohann and Treumann, 1996). Except few extreme cases, our selection of 12 min crossing data includes only the measurement of the inner central plasma sheet.

For obtaining the magnetic profile of the current sheet, the Cluster 2001 and 2002 tail seasons (July–October) data are used here. Events are selected from each single s/c crossing. Altogether there are 254 crossings. Of them, 172 cases are from northern hemisphere to southern hemisphere and 82 cases are from south to north. The spatial distribution of the intervals of current sheet observations is shown in GSM coordinates in Fig. 1. Good coverage of the current sheet is obtained, except for a slight bias along the dawn-dusk direction. On the dawn side, most the events are in the positive Z quadrant, while in the dusk side the events tend to the negative Z quadrant. Ultimately, the distribution of the event spatial locations is determined by the orbit of the spacecraft and location of the plasma sheet.

By using four spacecraft measurements, the current density can be calculated. To obtain a statistical current profile of the current sheet, we use the 2001 FGM data only when the inter-spacecraft distance is about 1800 km. In 2002 the inter-spacecraft distance in the magnetotail was about 4000 km and the accuracy of the current calculation decreases. For event selection, we used only those 12-min intervals when all four spacecraft monotonously crossed the well-defined current sheet in middle of these intervals. Altogether we have found 18 events from July to October 2001 to satisfy our criteria.

3. Results

Fig. 2 displays the magnetic field profile of the current sheet from all 254 selected crossings. The magnetic field components are plotted in GSM coordinates, as functions of minutes from the current sheet crossing, i.e., the distance to the current sheet. Events are selected from each single s/c crossing. It is clear that the current sheet crossings range from very fast crossings to slow crossings. In slow crossings, which represent most of the cases, the spacecraft stays in the current sheet for the whole 12 min, indicated by the low Bx value at begin and end of the crossing interval. With our event selection criteria, we also included some very fast current sheet crossings when the spacecraft cross the entire plasma sheet from lobe to lobe during the 12 min interval.

Fig. 3a shows magnetic Bx component for all 254 selected crossings, transposed into the same current sheet crossing direction. To produce a statistical profile, we average the data in 80 second bins by moving each 40 second. In Fig. 3b, solid diamonds are the averages of these 80 second bins where each bin includes 5334 data points. The black line is the Harris model best fit to the averages. It is clear that the averaged structure of the current sheet fits well with the Harris current sheet description. However, such a Harris model best fit results in a “lobe” field of 7.3 nT which is obviously underestimated. A possible explanation is that we have fitted only the inner current sheet layer embedded inside a thicker current sheet.

As stated above, for the statistical current density profile of the current sheet, we use only 18 events from 2001 when all four spacecraft monotonously crossed the well-defined current sheet in middle of these intervals. In order to construct an current density profile as functions of the transverse distance from the current sheet, we select a local normal coordinate system where Z* is the effective distance from current sheet centre along the normal direction (Runov et al., 2005). This Z* is calculated by integration of the linearly estimated magnetic field gradient with a 4 s step. Further we obtain the effective cross-tail current by project the total current calculated from curl B to Y* direction in our local normal coordinate. The average of the Bx* magnetic field profile is shown in the upper panel of Fig. 4. The solid points are the average of 800 km bins and we have moved the average bin by each 400 km. The line is simply the connection of these average points. The error bar indicates the probable error of the mean. The average magnetic field profile indicates a completely crossing of the current sheet. This profile is different than the magnetic field profile obtained earlier in Fig. 3 where events are selected from single s/c crossing. The average cross-tail current as functions of the vertical distance from current sheet center is shown in the lower panel Fig. 4. The cross-tail current is peak in a region about 0.5 Re thick with a maximum current intensity of 2.7 nA/m². The corresponding time of 12 min is about 1 Re in Fig. 4. Thus, our selection criteria results in an effective flapping velocity of the current sheet about 10 km/s.
4. Concluding remarks

In the present paper, we use Cluster magnetometer data to examine the structure of the current sheet. We found that the current sheet, on average, has a central single peak profile, resembling a Harris-type structure, with a maximum current density of 2.7 nA/m². However, the peak of the current density is narrower than Harris-type, and

Fig. 2. The magnetic field profile of the current sheet from all 254 selected crossings. The magnetic field components are plotted in GSM coordinates, as functions of minutes from the current sheet crossing. Events are selected from each single s/c crossing.

Fig. 3. (a) Magnetic field $B_x$ component of the current sheet from all 254 selected crossings which have been sorted into same current sheet crossing direction. (b) Solid diamonds are the average of 80 second bins by 40 second moving step. The black line is the Harris model best fit of the averages points.

4. Concluding remarks

In the present paper, we use Cluster magnetometer data to examine the structure of the current sheet. We found that the current sheet, on average, has a central single peak profile, resembling a Harris-type structure, with a maximum current density of 2.7 nA/m². However, the peak of the current density is narrower than Harris-type, and
may be described as embedded layer inside thicker current sheet. Thus, the statistical analysis show, that according to our selection criteria, even during quiet geomagnetic peri-
ods, the current sheet may contain an embedded layer of high magnetic gradient in the vicinity of the current sheet. Our result is significantly different than the recent papers of about the bifurcated current sheets (Hoshino et al., 1996; Nakamura et al., 2002; Sergeev et al., 2003; Runov et al., 2003a,b; Asano et al., 2004). A possible explanation is that we chose to use 12-min intervals when the spacecraft monotonously crossed the current sheet, which automatically excludes any current sheet crossing with oscillation period less than 24 min. We note that although the bifurcated current sheet occurs either with or without fast flow, it often associated with active thin current sheets with fast oscillations of several minute periods (Runov et al., 2003a; Sergeev et al., 2003). In contrast, our selection criteria results in an effective velocity of the current sheet about 10–20 km/s. With such a velocity, the equivalent thickness of this 12 min current sheet is about 1–2 Re. Thus our statistical represents a less active thick current sheet profile which is well described as Harris-type.

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Fig. 4. The average of the Bx magnetic field profiles of the 18 selected events is shown in the upper panel. The abscissa is the effective distance Z* from current sheet centre along the normal direction. The low panel shows the average cross-tail current as functions of the vertical distance from current sheet centre.