OBSERVATIONAL SIGNATURES OF CONSECUTIVE RECONNECTION PULSES

S. Posratschnig[1], V. S. Semenov[2], M. F. Heyn[1], I. V. Kubyshkin[2], S. A. Kiehas[3]

[1]Institute of Theoretical and Computational Physics, Technische Universität Graz, Petersgasse 16, A-8010 Graz, Austria, e-mail: posse@sbox.tugraz.at; [2]St. Petersburg State University, Petrodvoretz, 198504 Russia; [3]Space Research Institute, Austrian Academy of Sciences, Schmiedlstraße 6, A-8042 Graz, Austria

Abstract. We investigate model data produced by several close reconnection pulses. It is shown that a series of such pulses tends to induce a clear trend in the time-evolution of x- and z-components of both, the magnetic field (B_x, B_z) and plasma velocity (v_x, v_z). Such signatures with a typical trend in time during pulse propagation occur only for moderate distances of the observer with respect to the current layer. In all other cases relatively close to the current layer, the observer will see the direct effect of every single pulse onto the behaviour of the in detail measured magnetic field and plasma velocity. On the other hand, far away, all pulses will join and will look like one single pulse in the observational data.

1 Introduction

For the interaction between the solar wind and the Earth's magnetosphere the reconnection process is in general very important. Petschek proposed in his work in 1964 a steady-state reconnection model as a possible explanation for this. It can be shown that a local dissipative electric field is generated in the diffusion region and produces the decay of a tangential discontinuity. In detail, the current sheet breaks into a thin boundary layer given by a system of nonlinear magnetohydrodynamic (MHD) waves. It collects plasma from the near flux tubes and accelerates the plasma to Alfvénic speed v_A. This kind of shock structure propagates then outward along the current sheet away from the diffusion region (Figure 1).

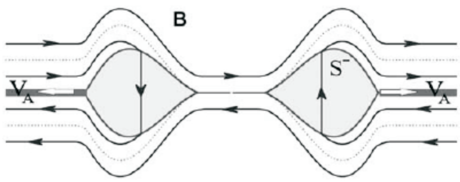

Fig. 1: Time-dependent Petschek-reconnection after Semenov et al. (2004) and Ivanova et al. (2007) in the switch-off phase. Heated and accelerated plasma is enclosed by the shocks (S^-). The magnetic field lines are connected via shocks. The dotted line represents the separatrix which confines the flux tube.

The magnetic field lines above and below the current sheet, which are initially antiparallel directed, are connected via the shocks, which form the outflow region (OR), illustrated by the grey areas in Figure 1. The surrounding area is then called the inflow region (IR), and the plasma flow has always the direction from IR into OR.

We know that nature is never ideal, and so reconnection appears often in form of an unsteady and patchy behaviour of impulsive character. Nevertheless, if we suppose a series of several pulses, we observe that the average reconnection flux can increase nearly linear like for steady-state reconnection with

$$E^* = \frac{1}{c}\frac{\partial F}{\partial t} \approx const.$$

Here E^* stands for the electric reconnection field and F is the magnetic flux per unit length along the X-line. If the time duration of the reconnection pulse is many Alfvén times, impulsive reconnection will look similar to a quasi steady-state reconnection.

In this paper we start with Petschek-like reconnection for a chain of pulses, and we investigate the trend in the magnetic field and velocity components. The tangential components are, in this case, "trivial", because they are not connected to the pulses. So we put our attention on the normal components. There exist two different regimes: a flux dominated (FD) and a shape dominated (SD). The shape dominated part shows the influence of the temporarily growing OR. Figure 2 shows the constant linear growth of the shocks and the separatrix which is the border of the flux tube surrounding the shocks.

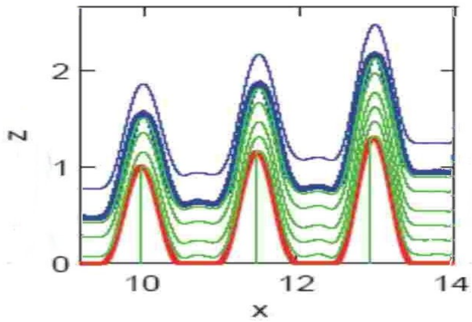

Fig. 2: Details of the shape of a series of impulsive multi pulses (in the first quadrant) which propagate in the x direction through space and the magnetic field line geometry influenced by it (thick red line the shocks; thick blue line separatix).

2 Model and calculations

From the ideal MHD equations and the Rankine-Hugoniot jump relations for an incompressible plasma with a constant density ρ, analytical solutions for impulsive reconnection can be found (similar to Semenov et al., 2004). The current sheet, based on a 2D geometry, is a tangential discontinuity, which separates two incompressible plasmas with oppositely oriented magnetic fields which are undisturbed and stationary at the beginning. Inside the diffusion region, the electric field $E^*(t)$ which is assumed to be much less than the Alfvénic electric field E_A, is an arbitrary function of time

$$E^* \ll \frac{1}{c} B_0 v_A = E_A,$$

and this electric field generates the movement of the discontinuities through the plasma along the current sheet. Here, c is the speed of light, B_0 is the undisturbed magnetic field and v_A stands for the Alfvénic speed. We derive the solution for this case from the ideal MHD equations, as described in Biernat et al., 1987. For the OR we use the solutions for each component of the plasma velocity, the magnetic field and the electric field, in the form,

$$v_x = v_A = \frac{B_0}{\sqrt{4\pi\rho}},\ v_z = 0,$$

$$B_x = 0,\ B_z = \frac{c}{v_A} E^* \left(t - \frac{x}{v_A} \right),$$

$$E_y = \frac{v_A}{c} B_z = E^* \left(t - \frac{x}{v_A} \right).$$

On the other hand, for the IR the vector components of the magnetic field and the plasma velocity must include perturbations, signed with index (1),

$$\vec{B} = (B_0 + B_x^{(1)}, B_z^{(1)}),$$

$$\vec{v} = (v_x^{(1)}, v_z^{(1)}).$$

The corresponding MHD solutions can be expressed through the following Poisson integrals

$$B_x^{(1)}(t,x,z) = \frac{1}{\pi} \int_{-\infty}^{\infty} d\xi \frac{(x-\xi) B_z^{(1)}(t,\xi,0)}{(x-\xi)^2 + z^2},$$

$$B_z^{(1)}(t,x,z) = \frac{z}{\pi} \int_{-\infty}^{\infty} d\xi \frac{B_z^{(1)}(t,\xi,0)}{(x-\xi)^2 + z^2},$$

and analogous expressions for $v_x^{(1)}$ and $v_z^{(1)}$ (Posratschnig et al., 2008).
The integral kernels at z = 0 we split into two parts: a flux dominated part (FP)

$$B_z^{(1)}(t, x, 0)_{FP} = \frac{c}{v_A} E^* \left(t - \frac{x}{v_A} \right),$$

$$v_z^{(1)}(t, x, 0)_{FP} = -\frac{v_A}{E_A} E^* \left(t - \frac{x}{v_A} \right),$$

and a shape dominated part (SP)

$$B_z^{(1)}(t, x, 0)_{SP} = \frac{c}{v_A} E^* \left(t - \frac{x}{v_A} \right) - \frac{c}{v_A^2} x E^{*\prime} \left(t - \frac{x}{v_A} \right),$$

$$v_z^{(1)}(t, x, 0)_{SP} = \frac{x}{E_A} E^{*\prime} \left(t - \frac{x}{v_A} \right).$$

All these expressions are valid for $x > 0$. For $x < 0$ the magnetic field can be continued as an odd function and the velocity as an even function.
All calculations are done using the time scale T_0, the time duration of the pulse, $v_A T_0 = L_0$, as a typical length of reconnection line (X-line), B_0, the initial magnetic field where v_A is Alfvénic velocity and $F_0 = v_A B_0 T_0$ the magnetic flux per unit length.

3 Results and discussion

The reconnection inducing electric field $E^*(t)$ can be chosen as an arbitrary function of time. We directly get Petschek steady-state solution, if E^* is constant.
For modelling the pulses we define for each pulse the same function

$$E^*(t) = \varepsilon \sin^2(\pi t), \ 0 \leq t < 1$$

$$E^*(t) = 0, \ t > 1.$$

Here we specified the electric field with $\varepsilon = |E^*|/|E_A| = 0.1$.

In all pictures, z defines the height of the observer above the current layer. Here we have put z = 1.2, because this is the intermediate distance where signatures of steady-state reconnection appear as shown in Posratschnig et al., 2008.

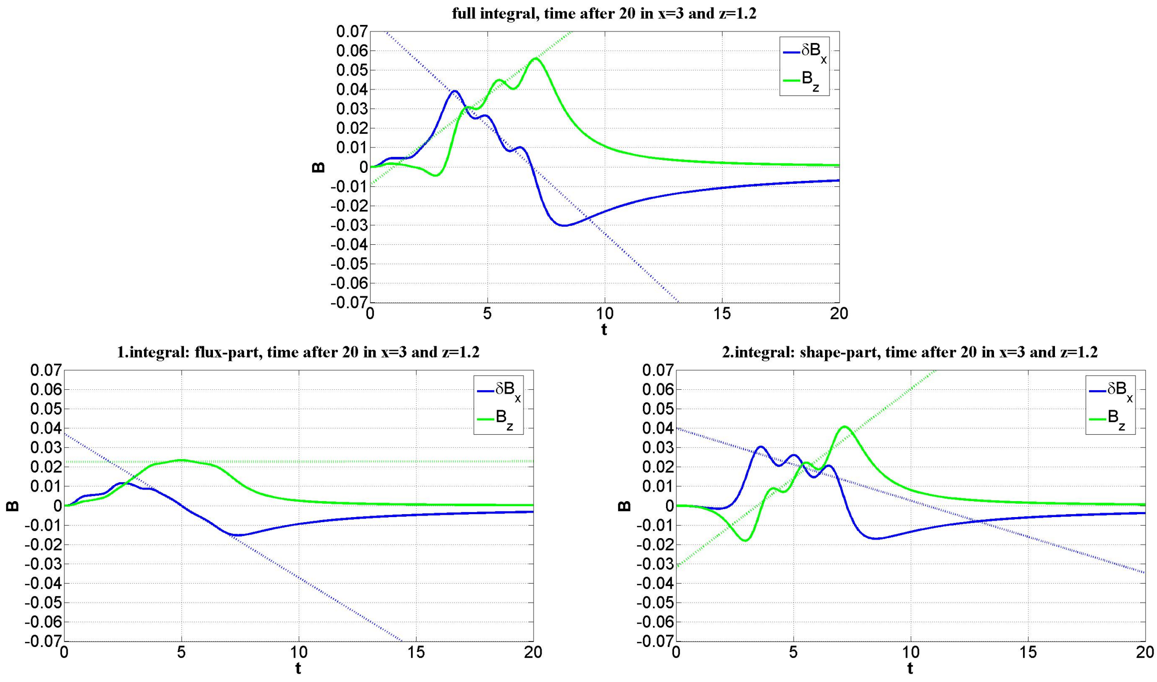

Fig. 3: Evolution of the magnetic field components δB_x (blue) and B_z (green) for a typical three pulse case. Also shown is the splitting of the results into FP and SP. The dotted lines describe the trend in time for the significant central part.

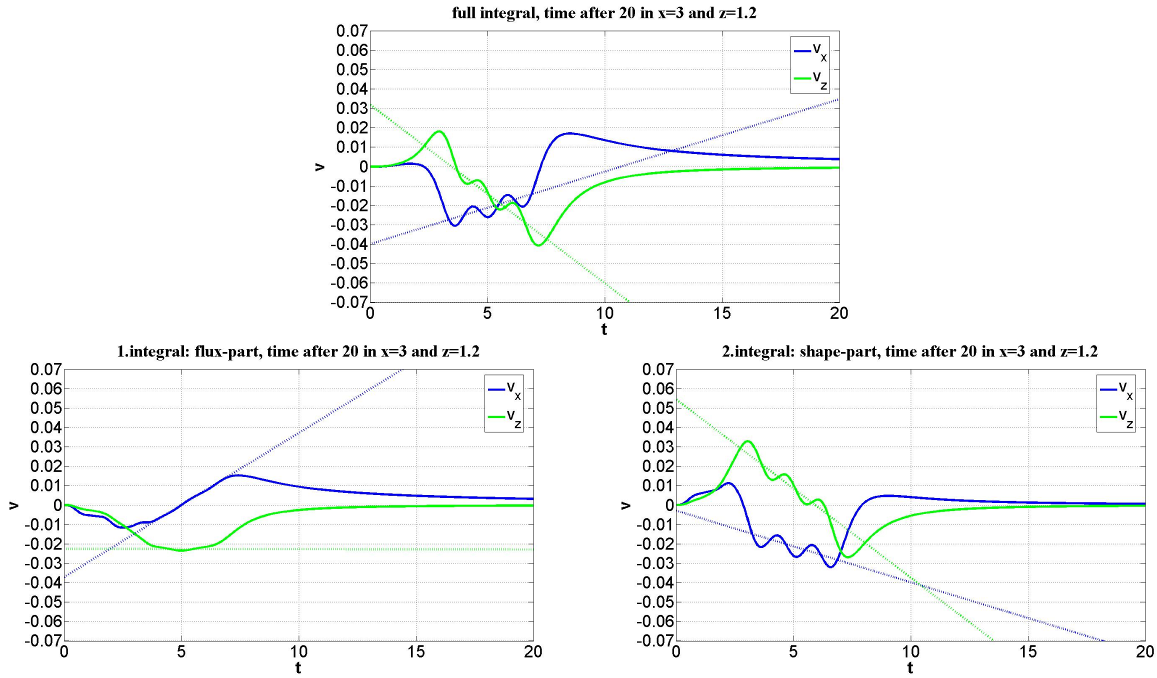

Fig. 4: Velocity components (above for the complete Poisson integral, below for FP and SP) for the three pulse case. The dotted lines are the trend in time for the significant central part even here.

Figures 3 and 4 show that the flux is more or less constant in the central part, so the trend starts to disappear for B_z and v_z. On the other hand, the shape dominated part has a strong slope in the trend because the growth of the shocks in time is caused by the fact that all the plasma is collected inside the OR.

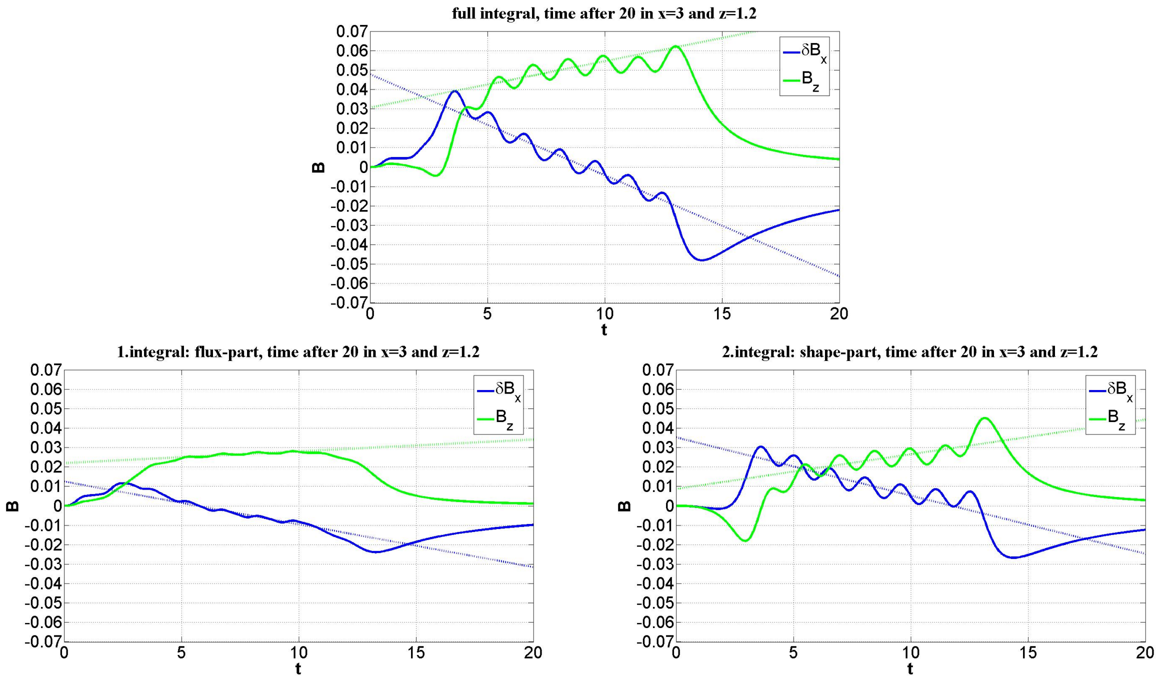

Fig. 5: Magnetic field components (above for the complete Poisson integral, below for FP and SP) for a case with seven pulses. The dotted lines describe the trend in time for the significant central part.

Also in Figures 5 and 6 we observe a clear trend in the normal components. In order to obtain trend lines we restrict the interval to the central part of the function. There we expect steady-state reconnection, because there the electric field E^* in average is practically constant as a consequence of the linear growth of the flux.

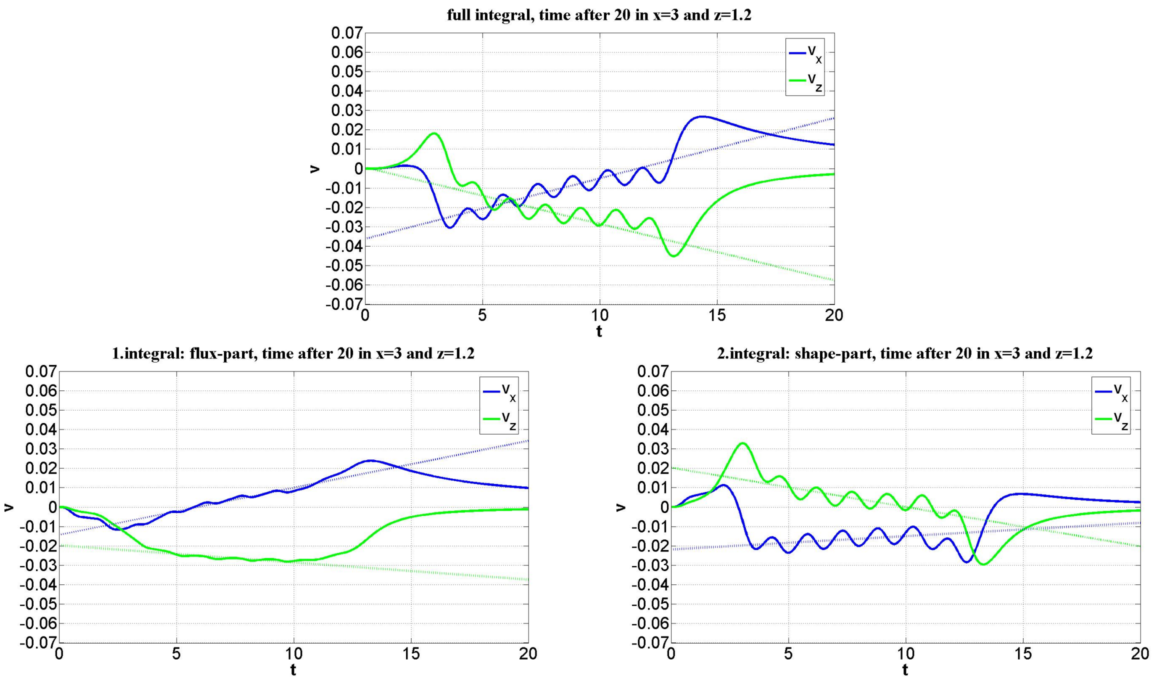

Fig. 6: Velocity components (above for the complete Poisson integral, below for FP and SP) for seven pulses. The dotted lines are the trend in time for the significant central part even here.

Thus, we are lead to the conclusion that the whole mechanism cannot be explained just by reconnection. Also, the growing of OR has a major influence.

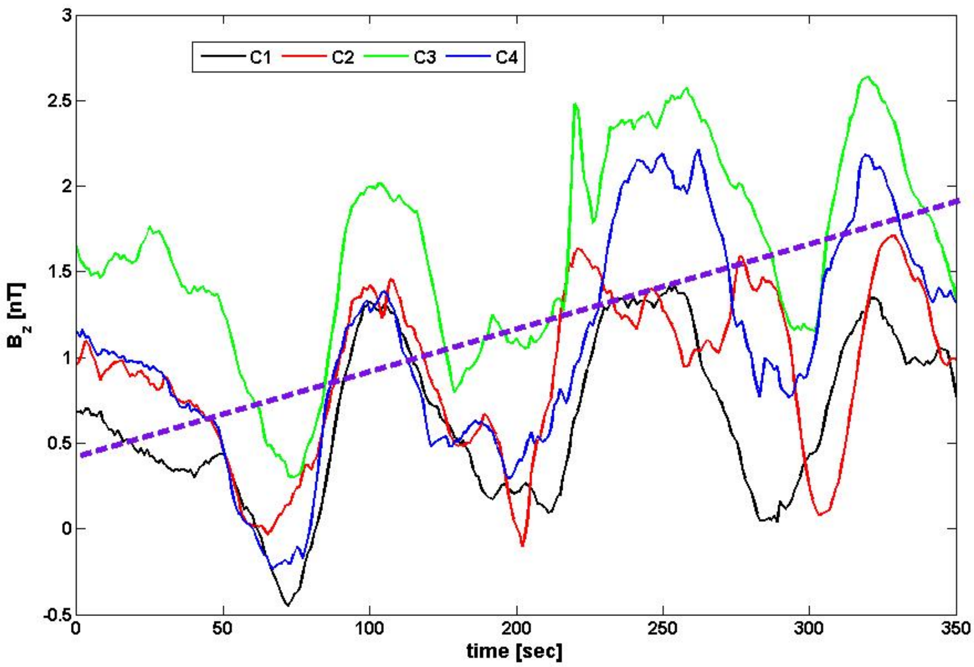

Fig. 7: Time series with three pulses of B_z, observed by four Cluster satellites.

In order to substantiate our supposition, we searched through satellite data. It is very intricate to identify a series of reconnection pulses. We did not find clear multi pulse reconnection events with coexistent trends in the x and z components, i.e. have negative and positive slopes at the same time. Figure 7 is a good example for three pulses, observed by Cluster satellites during a series of nightside flux transfer events on September 8th in 2002. The data have been investigated in detail in Sergeev et al., 2005 and in Kiehas et al., 2008. In these data, the trend of the z component of the magnetic field actually shows a positive slope in agreement with our prediction.

4 Conclusion

- We find for the case of intermediate distances z $\sim 1.2\ v_A T_0$ from the current layer, that the profile of the signatures for the multi pulse case are dominated by the shock shape rather than the reconnected flux.
- A closer look on the differences in the components shows, that B_z and v_x typically have an increasing trend characteristics in time, and B_x and v_z behave vice versa.
- It is difficult to find multi pulse reconnection events in satellite data which have the suggested upward trend in B_z and a coexistent downward trend in B_x. Nevertheless the search for such events is still going on.

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