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Transient reconnection caused by non-homogenous dynamic pressure*

LIU Zhenxing (刘振兴) and CHEN Tao (陈 涛)
(Center for Space Science and Applied Research, Chinese Academy of Sciences, Beijing 100080, China)

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Abstract It is proposed that local and transient reconnection in the plasma boundary layer can be caused by the impact and switch-off of non-homogenous dynamic pressure. Magnetohydrodynamic simulation is used to investigate the reconnection processes in these two cases. It is found that if the inflow is homogeneous, the reconnection will not take place; if the inflow is a shearing flow, no matter how great the shear of the flow is, the reconnection can be caused either during or after the impacting period. It is pointed out that a sudden stop of external force may be an important triggering mechanism of energy transformation and reconnection in the plasma boundary layer region.

Keywords: plasma boundary layer, dynamic pressure impact, transient reconnection.

In space physics, especially in space plasma physics, magnetic field reconnection is a very fundamental process related to the sudden change of magnetic field topology, energy conversion, heating and acceleration of particles. Up to now, there have been various reconnection models under different conditions. Parker[1], Petschek[2] and Sonnerup[3] presented their own steady-state reconnection models. Another kind of reconnection model is transient reconnection model which is relevant to time. Since the finding of flux transfer event[4], Lee and Fu[5] proposed a "multiple X lines reconnection" (MXR) model, Scholer[6] and Southwood et al.[7] proposed a "burst single X line reconnection" (BSXR) model, and Liu and Hu[8] proposed a "vortex-induced reconnection" (VIR) model. MXR is caused by tearing-mode instability driven by homogeneous flows on both sides of the current sheet. BSXR is caused by a sudden enhancement of anomalous resistivity. VIR is induced by fluid vortex generated by field-aligned shear flow. In a realistic space plasma environment, plasma boundary layer is not all the time compressed by the flows from both sides, but is sometimes compressed by the non-homogeneous dynamic pressure of the flow from one side. The reconnection process under external force used to be studied with the energy conversion and transient reconnection process after the removal of external force being neglected. We suppose the impact of transverse shear flow (TSF) generated by non-homogeneous dynamic pressure on the boundary layer and its stop may be an important mechanism to trigger transient reconnection in boundary layer. This reconnection mechanism is quite different from previous transient reconnection models, such as MXR, BSXR and VIR. We call it transverse shear flow driven reconnection (TSFDR) model.

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1 Simulation model

The main purpose of this paper is to discuss the reconnection configuration, evolution processes and physical mechanism of TSFDR by numerical simulation. A two-dimensional compressible magnetohydrodynamic (MHD) simulation method is used to study transient reconnection process and the structure of the field and the plasma in the plasma boundary layer region caused by the impact and switch-off of a non-homogeneous pressure. The simulation domain is a boundary layer region which includes a magnetosheath region (region I), a magnetopause region (region II) and a magnetosphere region (region III) as shown in figure 1.

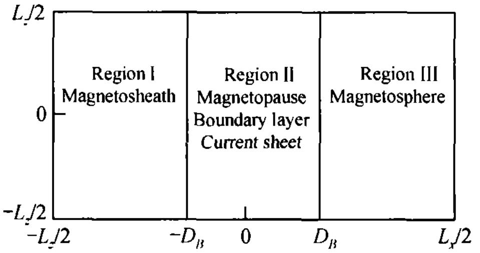

Fig. 1. Diagram of simulation domain, the horiontal line taken as x axis and the vertical line z axis.

The two-dimensional and compressible MHD equations are used in the simulation. The simulation domain is assumed to be a rectangle with $-L_x/2 < x < L_x/2$, and $-L_z/2 < z < L_z/2$, on the (x, z) plane. The initial values of velocity, magnetic field, temperature and density are assumed to be $V_x(x, z) = 0$, $V_z(x, z) = 0$, $B_x(x, z) = 0$, $T(x, z) = 1$ and $B_z(x,z) = \frac{(B_{02} + B_{01})}{2} + \frac{(B_{02} - B_{01})\tanh\left(\frac{x}{D_B}\right)}{2}$, where B_{01} and B_{02} are the magnitudes of magnetic fields in region I and region Ⅲ respectively, D_B is the thickness of magnetic field shear layer. According to the pressure equilibrium condition, the initial distribution of plasma density can be written as $\rho(x,z) = n_0 M_p + \frac{B_0^2 - B^2(x,z)}{2RT}$, where R is gas constant. At upper and lower boundaries, $z = +L_z/2$ and $z = -L_z/2$, the boundary conditions are periodic in z direction, while the boundary conditions imposed at $x = +L_x/2$ and $x = -L_x/2$ are fixed. On the left boundary of the simulation domain ($x = -L_x/2$), the transverse velocity (V_x) is assumed as $V_x\left(\frac{-L_x}{2}, z\right) = V_{x0} + V_{x1}\,\mathrm{sec}h\left(\frac{z}{D_v}\right)$, where V_{x0} is regarded as the background flow, V_{x1} the net shear flow, and D_V the velocity shear width. All other values on the boundaries can be obtained according to the initial condition.

In the simulation, we set a mesh system of (32 × 32) grid points, use the central difference formulas to replace differential derivatives and adopt the fourth order Runge-Kutta scheme. The space step Δx and Δz are taken to be 0.1 and 0.5 respectively.

In order to examine the accuracy of simulation results with (32 × 32) grids points, we have also simulated the evolution of magnetic field and flow field by using (128 × 128) grid points. It is found that both the simulation results are very consistent with each other. So, we believe that the simulation results with (32 × 32) grid points in this paper are reliable.

2 Simulation results

The parameters used in the simulation are $T_0 = 3.27 \times 10^6$ K, $n_0 = 20/\mathrm{cm}^3$, $L_0 = 1\,500$ km,

$B_0 = 20$ nT, $V_0 = \sqrt{RT_0} = 232.49$ km/s, $\eta = 0.0004$ (the first fluid viscosity coefficient $\nu = 3.54 \times 10^{16}$ s·m/kg), $\eta_m = 0.008$ (electrical conductivity $\sigma = 2.85 \times 10^{-4}$[ohm. m]), adiabatic index $\gamma = 5/3$, $V_A = 97.6$ km/s, $t_A \cong 15$ s. We take $B_{02} = 1.2B_0$, $B_{01} = -0.6B_0$, and assume $D_V = 600$ km. Now we display several evolutions of magnetic field topology and flow pattern caused by different flows in the following cases.

2.1 Magnetic reconnection under the impacting of shear flow

In the simulation we take $V_{x0} = 0.01\,V_0$ and $V_{x1} = 0.1\,V_0$, with all other parameters given as before. Evolution of field topology and flow state is displayed in fig.2. It is shown that the magnetic field lines in region I become gradually bent due to the rushing of TSF and form a reversed magnetic field region, and the region goes on to extend to the current sheet region. There appears a magnetic island in the reversed magnetic field region. At about $t = 7t_A$, reconnection occurs in the current sheet region due to the incessant rushing of the shear flow. A "reverse K" type quasi-steady reconnection structure is formed gradually and the neutral point is located in the part near region Ⅲ, which is rather different from that of classical reconnection. It also shows that a jet-like flow is formed in the reversed magnetic field region near $z = 0$ line. The configuration of flow is symmetrical to $z = 0$ line according to the boundary conditions. We can find that the final quasi-steady configurations of magnetic field and flow are analogous for different impacting times.

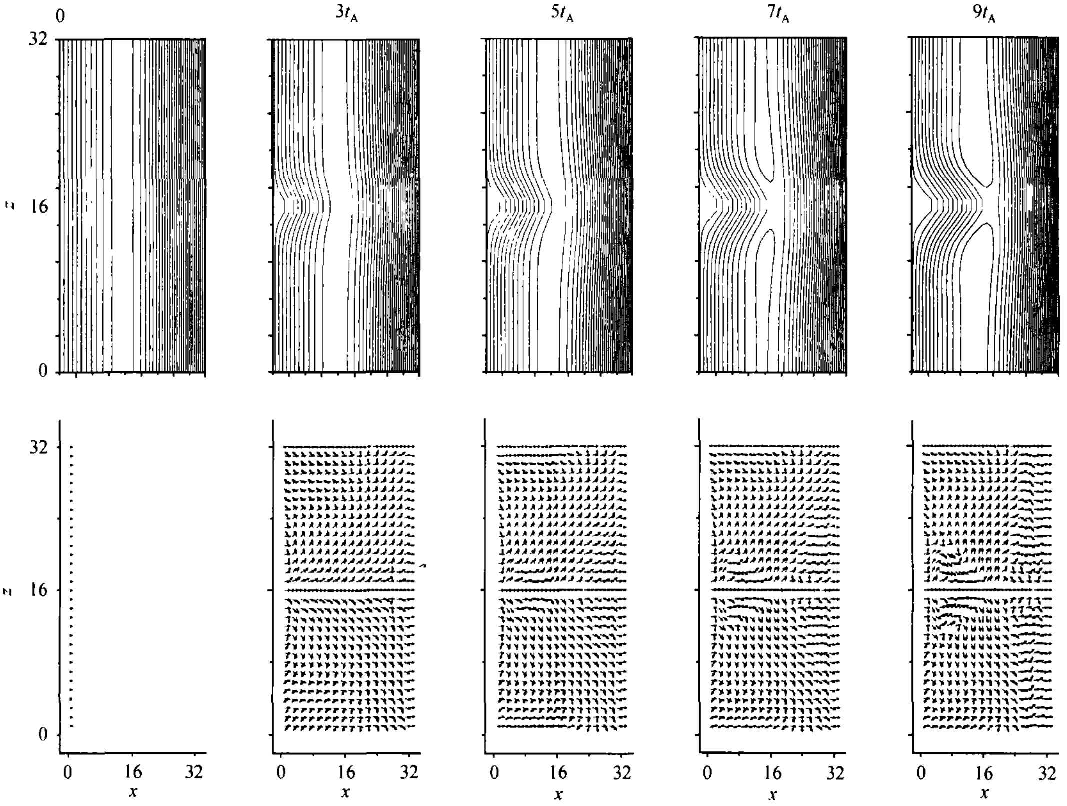

Fig. 2. Evolution of field and velocity during the period of TSF impact. The horizontal line is x axis, the vertical line is z axis, the units of x and z are Δx and Δz. Uppor row: magnetic field lines; lower row: velocity vectors.

2.2 Magnetic reconnection after impacting stops

In this section, we will discuss the transient reconnection after the TSF stops. Let the TSF stop suddenly at $t = 11.4\ t_A$. t is the time at which the TSF is switched off. The evolution time after external flow impact stops start to be calculated from $t = 0t_{\mathrm{A}}$. The evolution of magnetic field and flow topology is presented in fig. 3, which shows that the reversed magnetic field configuration in region I disappears fast. The "reverse K" type structure gradually becomes a strong single x line reconnection configuration located in the central part of the current sheet ($t = 38t_{\mathrm{A}}$), while the current sheet moves toward left and the reconnected lines are pulled out by flow. Later, the transient reconnection topology becomes a multiple x reconnection structure (at $t = 145\ t_{\mathrm{A}}$), then a weak single island structure (at $t = 251t_{\mathrm{A}}$). Further more, a strong single x line reconnection structure appears again (at $t = 425t_{\mathrm{A}}$). At around $t = 600\ t_{\mathrm{A}}$, the field topology returns to the undisturbed state. In this process, the location of the current sheet moves gradually toward right once again. It is also found that the magnetic field lines in regions Ⅰ and Ⅲ oscillate in opposite phase.

After TSF stops, the flow pattern changes obviously. Two large reversed symmetrical vortices in the current region and other two vortices in region Ⅲ are formed respectively at about $38\ t_{\mathrm{A}}$, and two opposite jet-like flows near the $z = 0$ line are generated on the both sides of current sheet. The two op-

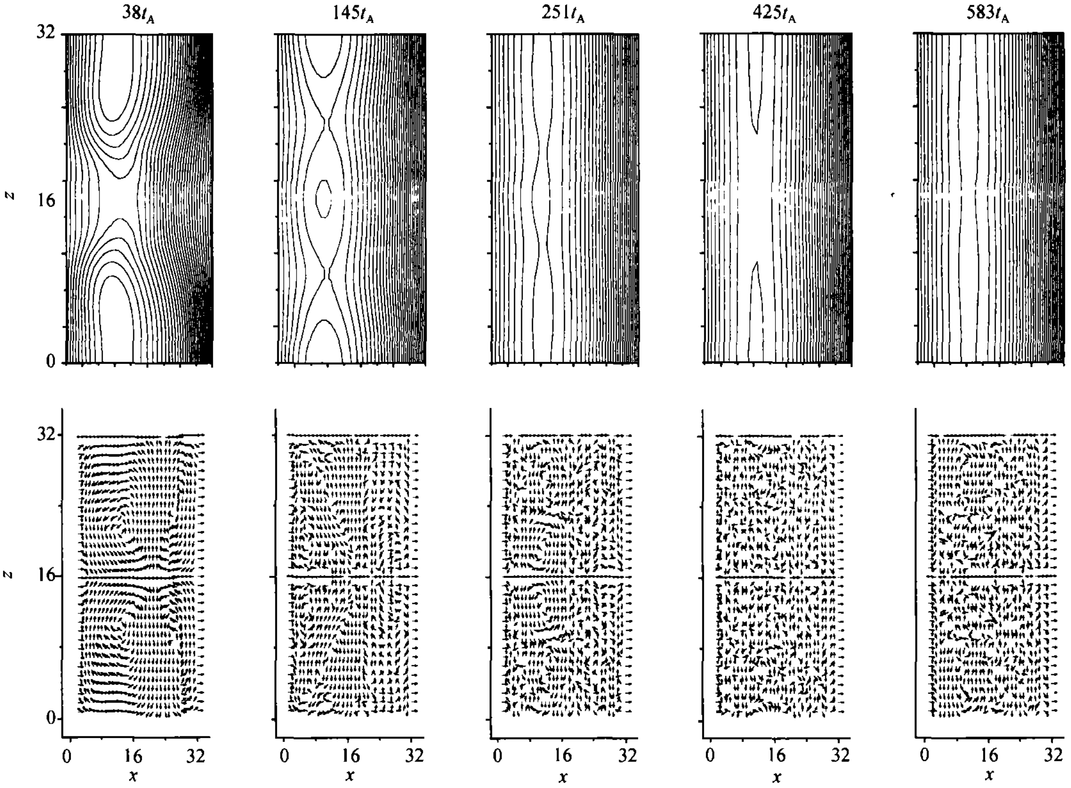

Fig. 3. Evolution of field and velocity after TSF impact stops, the horizontal line is x axis, the vertical line is z axis, the units of x and z are Δx and Δz. Upper row, magnetic field lines; lower row, velocity vectors.

posite inflows impact the current sheet to generate a strong single x line reconnection at $t = 38\ t_A$. Then the structure of vortices in the current sheet changes gradually, the jet-like flow in region Ⅱ near $z = 0$ line gradually weakens, and the flow changes to an opposite direction at $t = 145\ t_A$, and the flows in regions Ⅰ and Ⅲ rush into the current region at the upper part and the down part region in the same time, and this flow structure generates a multiple x line reconnection configuration. At $t = 245\ t_A$, vortex structure is similar to that of $t = 38\ t_A$. In this case, a single x line reconnection has occurred again and gradually enhanced. Then the vortices become larger gradually, until $t = 425\ t_A$, Finally, the flows in the simulation domain become irregular and turbulent. During this period, the magnetic field configuration gradually returns to the undisturbed state.

3 Discussion

According to the simulation results, an alternative transient reconnection model (TSFDR) is presented. This model is very different from MXR model, VIR model and BSXR model. MXR is caused by homogeneous transverse flows from both sides of a current sheet driven tearing mode instability, VIR by the vortex formed in parallel shear flow and BSXR is caused by a sudden increase of local anomalous resistivity, while TSFDR model is caused by the impact of a single directed transverse shear flow and inner flow disturbance after the rushing suddenly stops.

We suggest that the reconnection mechanism proposed in this paper may exist in some regions of space plasma, such as the subsolar point region of dayside magnetopause. The more detailed analysis of plasma and field structure and the application of this reconnection model in space physics, will be covered in other papers.

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References

1 Parker, N.E., Sweet's mechnism for merging magnetic fields in conducting fluids, *J. Geophys. Res.*, 1967, 62: 509.
2 Petschek, H.E., Magnetic field annihilation, *AAS-NASA Symp. Solar Flares*, 1964, Sp-50: 425.
3 Sonnerup, B.U.O., Magnetic field reconnection in a highly conducting incompressible fluid, *J. Plasma Phys.*, 1970, 4: 161.
4 Russel, C. T., Elphic, R. C., Initial ISEE magnetometer result: magnetopause observations, *Space Sci. Rev.*, 1978, 4: 681.
5 Lee, L.C., Fu, Z. F., A theory of magnetic flux transfer at the earth's magnetopause, *Geophys. Res. Lett*. 1985. 12: 105.
6 Scholer, M ., Magnetic flux transfer at the magnetopause based on single x line burst reconnection, *Geophys. Res. Lett.*, 1988, 15: 291.
7 Southwood, D. J., Farrugia, C. J. Sauders, J., What are flux transfer events, *Planet. Space Sci.*, 1988, 36: 504.
8 Liu, Z. X., Hu, Y.D., Local reconnection caused by vortices in the flow field, *Geophys. Res. Lett.*, 1988, 15: 752.