

EXPERIMENTS ON MAGNETIC RECONNECTION IN 3D CONFIGURATIONS WITH X-LINES

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Magnetic reconnection phenomena can take place inside high-conductive magnetized plasma at some discrete regions that separate magnetic fields of different (or opposite) directions and where the electric current and plasma are concentrated. These regions assume usually a shape of current sheets (CS). Thus magnetic reconnection problem, which is of a fundamental importance for both astrophysical and laboratory plasmas, is closely related to the possibilities of CS formation. Magnetic configurations with singular lines of the X-type hold a unique position among a variety of 3D configurations. Magnetic field \mathbf{B}_t in a vicinity of the X-line is usually reported as a combination of two magnetic fields, one is 2D field \mathbf{B}_\perp with a null-line and radial gradient h , another is a uniform field B_\parallel applied along the null-line:

$$\mathbf{B}_t = \{hx; -hy; B_\parallel\} \quad (1)$$

We studied experimentally plasma dynamics in magnetic configurations with X-lines and possibilities of CS formation after an electric current I_z was excited along X-line. This gave an opportunity to reveal characteristics of initial current-free magnetic configurations, which are necessary for the CS formation; some parameters of CS were established as well.

A principal diagram of the device is displayed in the Fig. 1. An initial quasistationary magnetic configuration (1) was produced by a superposition of two fields (see above); pa-

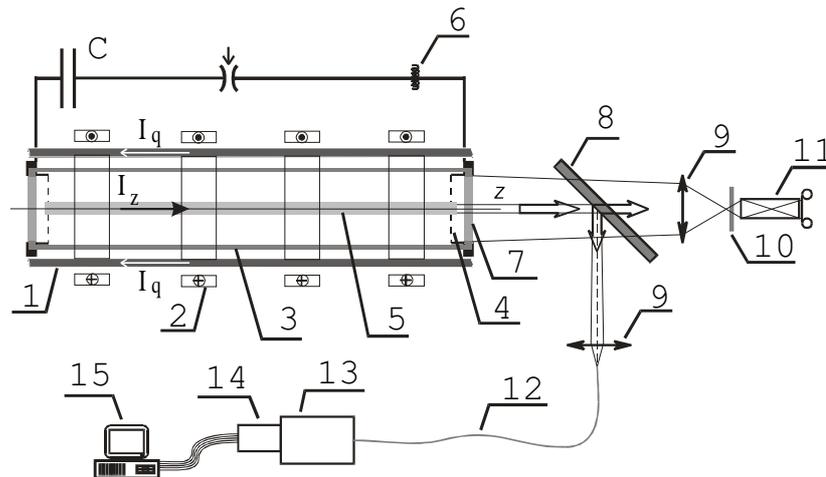


Fig.1. Experimental device “3D Current Sheet” and diagnostics. 1-straight conductors for generation of 2D magnetic field with a null-line at Z-axis. 2- four coils for generation of a uniform magnetic field B_\parallel . 3-quartz vacuum chamber $\varnothing=18$ cm, $l=100$ cm. 4- meshed electrodes. 5- current sheet. 6-Rogowskii coil. 7- quartz windows. 8-50% mirror. 9-lenses. 10-interference filter. 11-frame camera. 12-quartz optical fiber. 13-monochromator. 14- multichannel optical registration system MORS-3. 15-PC-486.

rameters of both fields (h and $B_{||}$) could be changed independently, providing a variety of configurations with gradual transitions between them. Vacuum chamber was filled with He-gas at 300 mTorr, an initial plasma with $N_{e0} \approx 10^{-16} \text{ cm}^{-3}$ was produced by an auxiliary θ -discharge. An excitation of plasma electric current I_z stimulated MHD-flows and could result in a CS formation and plasma compression, as was observed previously in 2D magnetic fields with null-lines [1]. Phenomena of this type were revealed recently in 3D nonuniform magnetic fields both with null-points and without them [2]. Contrary to papers [2], we concentrated now on magnetic configurations with Z -translational symmetry. A frame-camera with interference filters was used to register plasma images in HeII and HeI spectral lines at successive stages of CS evolution [3]. Electron concentrations in the CS midplane and in peripheral regions were derived from the profiles of HeII and HeI spectral lines [4].

First round of experiments was carried out under conditions when all initial parameters including $B_{||}$ field were kept constant, with the exception of the gradient h : it was varied to produce different magnetic configurations with X-lines. Plasma shapes could be followed

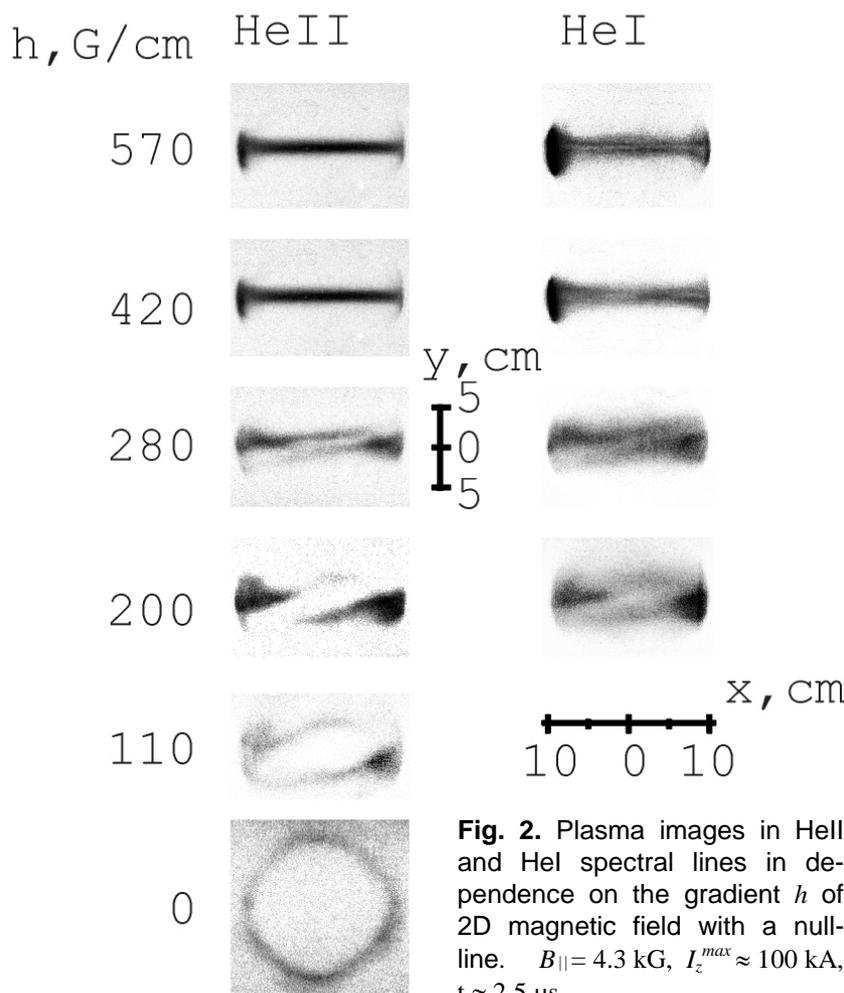


Fig. 2. Plasma images in HeII and HeI spectral lines in dependence on the gradient h of 2D magnetic field with a null-line. $B_{||} = 4.3 \text{ kG}$, $I_z^{max} \approx 100 \text{ kA}$, $t \approx 2.5 \mu\text{s}$.

from the HeII and HeI images, Fig. 2. There is a kind of a demarcation line that divided initial configurations in two parts. CS formation was observed under higher values of h while the process did not occur under lower h . Two upper pairs of images in the Fig.2 displayed the formation of plane CS, which looked much like the CS evolving in a pure 2D magnetic field ($B_{||}=0$): HeII was of a maximal intensity at the middle plane ($y=0$) and HeI burnt out there [3]. It is important that $B_{||}$ exceeded the transverse

field B_{\perp} in the most part of the plasma volume; nevertheless there were no obstacles from CS formation.

At the same time the concentration of electrons inside the sheet proved to be lower in a presence of B_{\parallel} field comparing with 2D magnetic configurations, Fig.3, so that B_{\parallel} appeared to

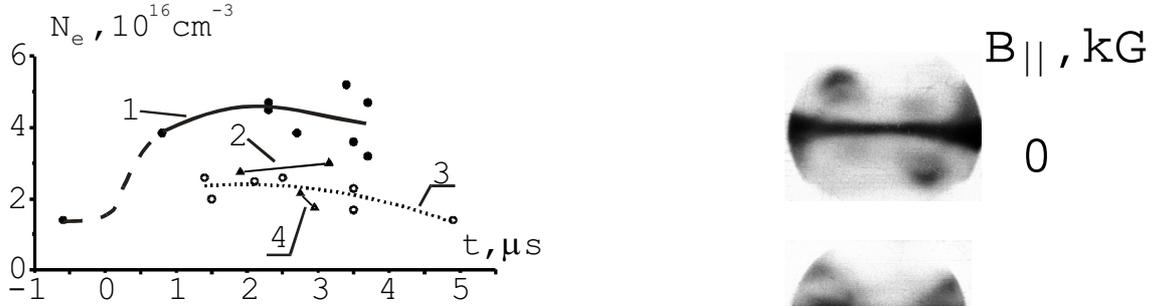


Fig. 3. Electron concentration in CS vs time derived from the profiles of HelII (curves 1,3) and HelI (2,4) spectral lines. (1,2) - $B_{\parallel}=0$; (3,4) - $B_{\parallel}=4.3$ kG; $h=570$ G/cm, $I_z^{\max} \approx 100$ kA.

Fig. 4. Plasma images in HelI spectral line in dependence on the strength of B_{\parallel} ; $h = 200$ G/cm, $I_z^{\max} \approx 40$ kA, $t \approx 2$ μ s.

prevent the plasma from efficient compression. Actually B_{\parallel} field might be transferred by plasma flows in a course of CS formation resulting in a production of extra B_{\parallel} field [5]. This field manifested itself as an additional gas-kinetic pressure and might increase a combined pressure inside CS. We estimated the extra B_{\parallel} field in the middle plane of CS as 80-90% of the initial B_{\parallel} value, so that $B_{\parallel}^{\text{sh}} \approx 8$ kG. Thus a degree of plasma compression went down with a rise of B_{\parallel} , displaying a gradual transition to the dynamics of incompressible plasma.

Next images in the Fig.2 made it apparent that no familiar CS appeared in a magnetic configuration with X-line under lower value of gradient h and constant strength of B_{\parallel} field. Instead of CS there were observed more or less elongated plasma configurations crossed by sloping splits that divided plasmas in two parts. Both plasma thickness and split width increased when h decreased. Thus some minimal gradient h was found to be necessary for the CS formation in configurations with X-line under a fixed strength of the longitudinal field B_{\parallel} .

To clarify combinations of B_{\parallel}/h that ensured the formation of CS, we kept constant the gradient h of 2D magnetic field and varied the strength of B_{\parallel} field, which was gradually increased from a top to a bottom in the Fig.4. Plasma images showed a transition from plane CS ($B_{\parallel}=0$; 1.4 kG) to elongated plasma configurations crossed by sloping splits ($B_{\parallel}=2.9$; 5.7

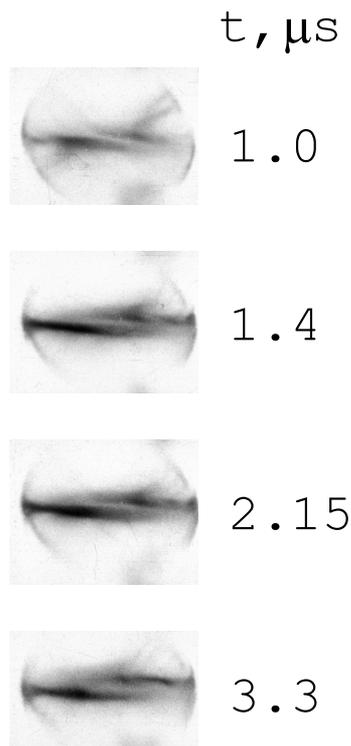


Fig. 5. Plasma images in Hell spectral line vs. time; $h=200$ G/cm, $B_{||}=5.7$ kG, $I_z^{\text{max}} \approx 40$ kA.

kG). By tracing a time evolution of plasma configuration we observed that plasma shape practically did not change and proved to be rather stable, Fig. 5.

It is essential that an evident destruction of CS occurred under a ratio $f = B_{||}/h \sim 15$ cm for the both cases presented in Figs 2, 4. So we could conclude that the parameter f was of a crucial importance for CS formation in magnetic configurations with X-lines. We suppose that the critical value f might be determined by geometry of any configuration with X-line.

Summary

- The formation of plane current sheets was observed experimentally in 3D magnetic configurations with X-lines, i.e. in the presence of fairly strong uniform magnetic field applied along X-line, including conditions when $B_{||} > |B_{\perp}|$ everywhere inside plasma volume.
- It was shown that the concentration of electrons inside the sheet became lower in the course of longitudinal field $B_{||}$ was increased. A fall in the degree of plasma compression displayed a gradual transition to the dynamics of the incompressible plasma
- It was revealed that the formation of current sheets was no longer possible if $B_{||}$ exceeded some critical value. Instead of the sheet there appeared two plasma envelopes separated by a distance, which depended on a relation between the gradient of 2D magnetic field h and the strength of $B_{||}$ field.

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