Global plasma dynamics during magnetic reconnection in the VINETA-II experiment

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Magnetic reconnection is thought to play an important role in many space plasma phenomena, e.g. solar flares, as well as in some laboratory processes, e.g. sawtooth crashes in tokamaks. Despite extensive research on magnetic reconnection, the underlying processes of particularly fast collisionless reconnection are under debate [1]. Diagnostics of reconnection in space and fusion devices is restricted either by technical limitations or harsh environments. Dedicated magnetic reconnection experiments bridge the gap between space and fusion experiments and enable a controllable environment which allows for a better understanding of the processes involved.

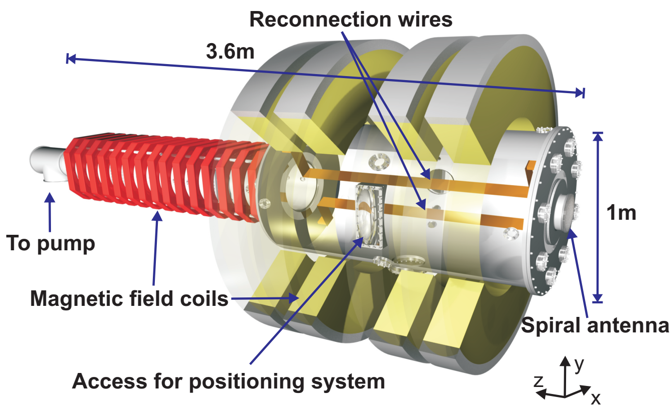

Figure 1: The VINETA-II Experiment

The linear magnetized plasma device VINETA has been adapted for the study of driven magnetic reconnection. The new setup, VINETA-II, is shown in figure 1. The upgrade consists of the addition of a stainless steel vacuum chamber with a diameter of 1m and a length of 1.6m. Reconnection is driven by passing an oscillating current ($f_{\mathrm{drive}} \approx 50$kHz) through two parallel conductors placed inside the module. A typical current trace of the reconnection drive current through the conductors is shown in figure 2. The large dimensions of the module and positioning of the conductors allow for a closed reconnection field line configuration, which helps reducing plasma transport to the walls along the reconnecting field lines. A homogenous axial guide field of $B \leq 100$mT is superimposed on the reconnecting magnetic field. Plasma is generated by inductive heating using a spiral antenna ($f_{\mathrm{rf}} = 13.56$MHz) which produces densi-

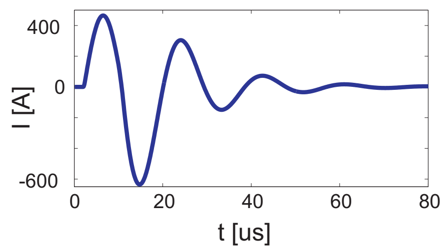

Figure 2: Current time trace of reconnection drive

ties in the range $n = 10^{16} - 10^{18}\mathrm{m}^3$ and electron temperatures of up to 6eV. This allows for the study of reconnection in a resistive MHD regime as well as nearly collisionless reconnection.

Essential to the study of reconnection is to obtain a detailed description of the electromagnetic fields and currents that, along with the evolution of plasma parameters such as temperature and density, characterize the system. Measurements of these quantities allow for the determination of the force balance on the system. The reconnection magnetic field is measured using induction coils, which consist of 0.1mm copper wire wound in 20 turn rectangular loops with an area of $2\mathrm{cm}^2$. The magnetic field probes can be scanned through the entire poloidal plasma cross section using a high precision positioning system. This allows for the determination of the highly reproducible spatiotemporal evolution of the magnetic field. The calculated 2D magnetic field according to the geometry of the reconnection wires, as well as the region of the measurement with the induction coils, is depicted in figure 3a. The magnitude of the field in vacuum measured with this setup is shown in figure 3b. The center point between the two conductors, where the magnetic field goes to zero, is clearly visible, and a good agreement was found between the calculated and measured magnetic field. The measurements of the magnetic field enables the determination of the time-evolution of the magnetic field lines via $\mathbf{B} = \nabla \times \mathbf{A}$. Through the frozen-in flux condition, this also yields the motion of the plasma. The magnetic field lines at three different time instants are shown in figure 4. The X-point geometry and the reconnection of the field lines can clearly be seen. The time-varying magnetic field is also associated with an induced axial electric field $\mathbf{E} = \partial \mathbf{A}/\partial t$, which drives axial plasma currents in the reconnection layer. The induced electric field, as determined from the temporal evolution of the magnetic field, is shown in figure 5a. The inductive field has a saddle point at the X-point, increasing towards the conductors and decreases towards the wall of the vacuum chamber. An independent in-

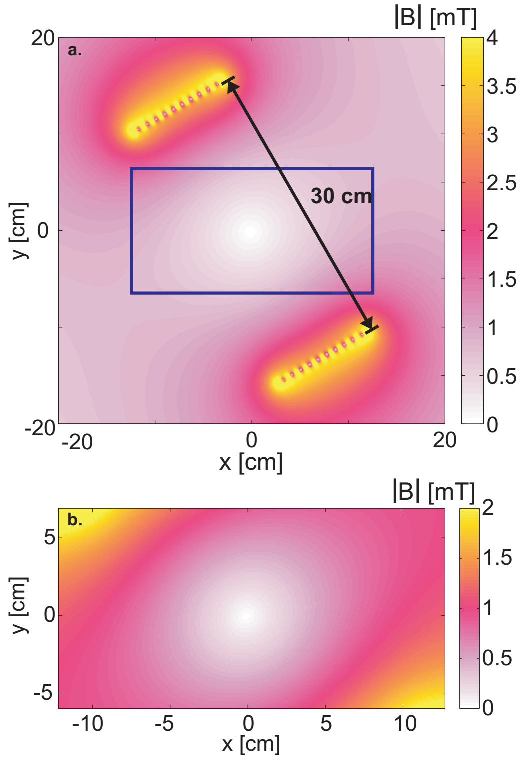

Figure 3: Calculated magnetic field of the reconnection wires for I= 600A, showing the region of the magnetic field measurement with the probe on the 2D positioning system (a). Amplitude of magnetic field at $t = 14.0\mu$s (b)

ductive field measurement was also made using a measurement of the loop voltage. This was done using two radially aligned wires connected by an axial wire with a length of $\Delta z = 1.4$m. The open loop voltage then arises only from the voltage V induced on the axial part of the wire and the induced electric field is given by $E = V/\Delta z$ [2]. The induced electric field goes towards zero at the wall of the vacuum chamber (figure 5b). This is due to the return currents of the drive current through the wall.

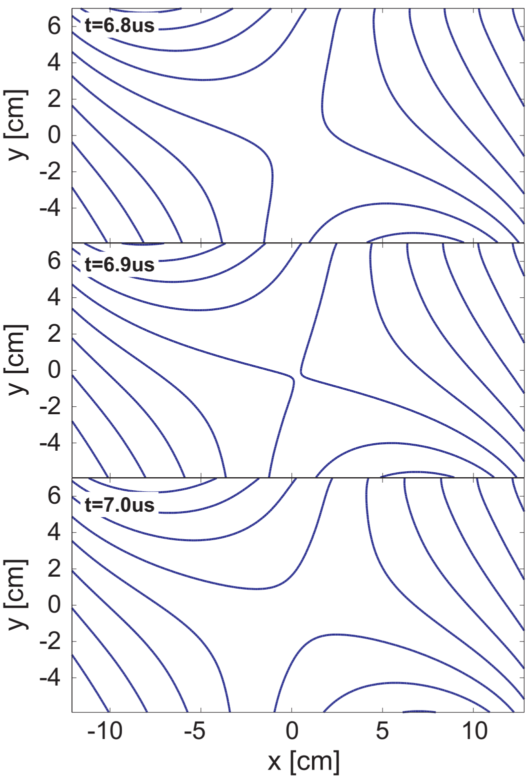

Figure 4: Time evolution of magnetic field lines (contours of constant vector potential)

For determining the axial current density, which is essential in order to determine shape and size of the current layer, two approaches will be used. One way is to simply take the curl of the magnetic field $\nabla \times \mathbf{B} = \mu_0 \mathbf{j}$. An independent measurement of the current density will also be made using a small Rogowski coil scanned through the plasma using the positioning system. The Rogowski coil has a minor radius of 1.3mm and a major radius of 2.7mm. As a test case, the current density is calculated from the inductive field, taking a spiral antenna discharge with density 10^{16}m^{3}and temperature of 6eV and assuming spritzer resistivity. This result is given in figure 6a. The current density has a maximum at the center, where the density and temperature are the highest, and has a steeper decrease towards the wall than towards the conductors as

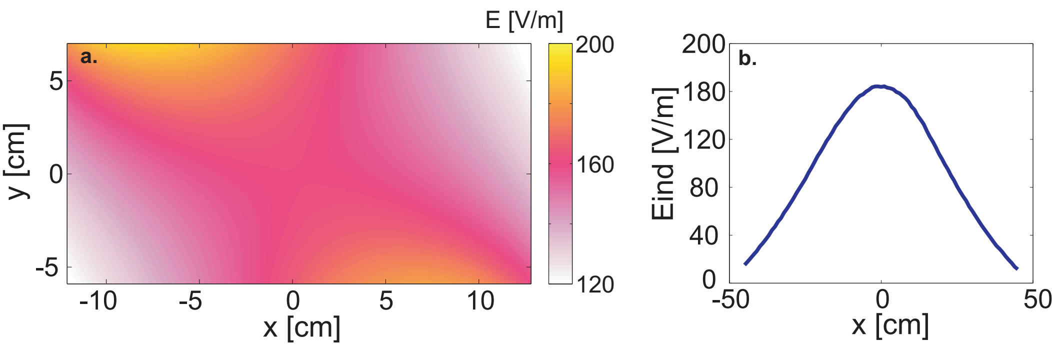

Figure 5: 2D Inductive field calculated from magnetic field measurement at $t = 17.4\mu$s (a.). Radial inductive field measured with the loop voltage (b.).

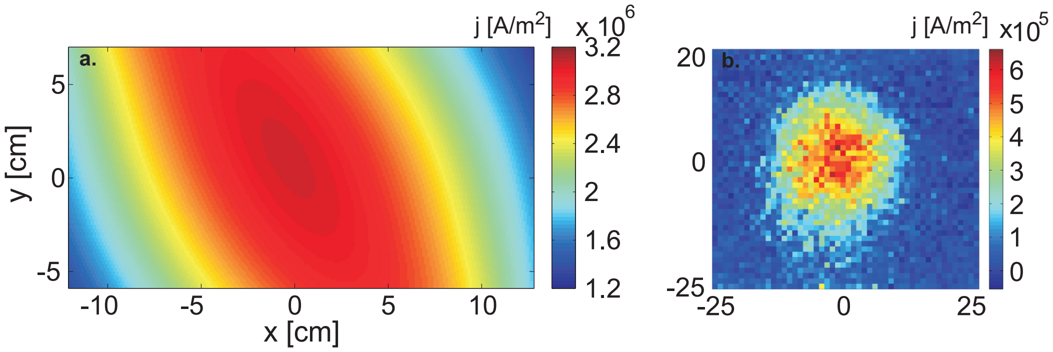

Figure 6: Estimate of current density based on the measured inductive field and spiral antenna discharge with a density of 10^{16}m^{3}and temperature of 6eV (a.). Current density profile of the plasma gun discharge as measured with a Rogowski coil (b.)

can be expected from the inductive field. This gives an idea of the lower bound of the current density, and has not taken into account the effect of the current on the magnetic field and hence the inductive field, which would result in concentrating the current in a small current layer at the X-point. Furthermore, due to the open end configuration of the experiment, and the build-up of an axial electrostatic field opposing the inductive field, the current becomes limited to the Bohm current. In order to counteract these limitations, an additional electron source is required. The approach in the VINETA-II experiment is to make use of a plasma gun for this purpose[3]. A test of the Rogowski coil as a diagnostics tool for determining the current density of the reconnection layer has been done by measuring the current density profile produced by a plasma gun discharge. The current is pulled from the plasma gun by a dc electric field produced by a positively biased metal plate with a diameter of 4 cm. The current density profile of the plasma gun is well resolved, as can be is seen in figure 6b.

References

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