Dynamics in the Current Sheet of the VINETA II Magnetic Reconnection Experiment

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Magnetic reconnection takes place in a narrow current layer between opposed magnetic fields as they occur in magnetospheric plasmas as well as in fusion experiments. Simple MHD models exist [1] which adequately describe reconnection in plasmas with low Lundquist numbers ($S = \mu_0 L v_A/\eta$), e.g. where resisitivity is high and the length scales are small. However, these models are not able to describe the abnormally high reconnection rates observed in nearly collisionless plasmas. A number of experiments and simulations exist in order to further investigate the processes involved in fast reconnection as, e.g. anomalous resistivity which arises through fluctuations [2], an increase of reconnection speed through two-fluid effects [3] and fully kinetic particle simulations [4].

VINETA II is a new modular cylindrical experiment for the study of magnetic reconnection in a well controllable laboratory environment. A schematic of the reconnection module is shown in fig. 1a). Poloidal field coils create a strong axial guide field ($B_{||} < 0.1\,\mathrm{T}$) which enables accompanying gyro-PIC simulations of the experiment. Plasma is created by rf antennae (helicon with a diameter of d =10 cm or spiral with d =20 cm) which allow for variation of the plasma density over three orders of magnitude ($n_e = 10^{16} - 10^{19}\,\mathrm{m}^{-3}$, $T_e < 6\,\mathrm{eV}$), thereby enabling the transition from a collisionality dominated to a collisionless reconnection regime. Reconnection is driven by two parallel conductors (peak current I =1 kA) which compress the magnetic field towards the central axis on a time scale of $\tau = 10\,\mu s$. The corresponding magnetic field in an

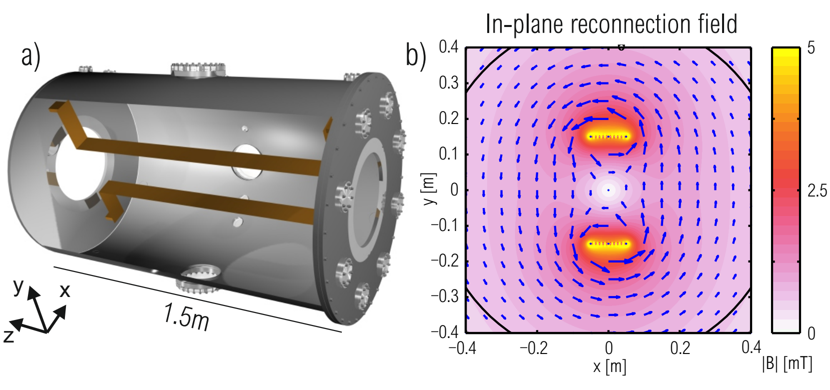

Figure 1: VINETA II reconnection module and in-plane magnetic field.

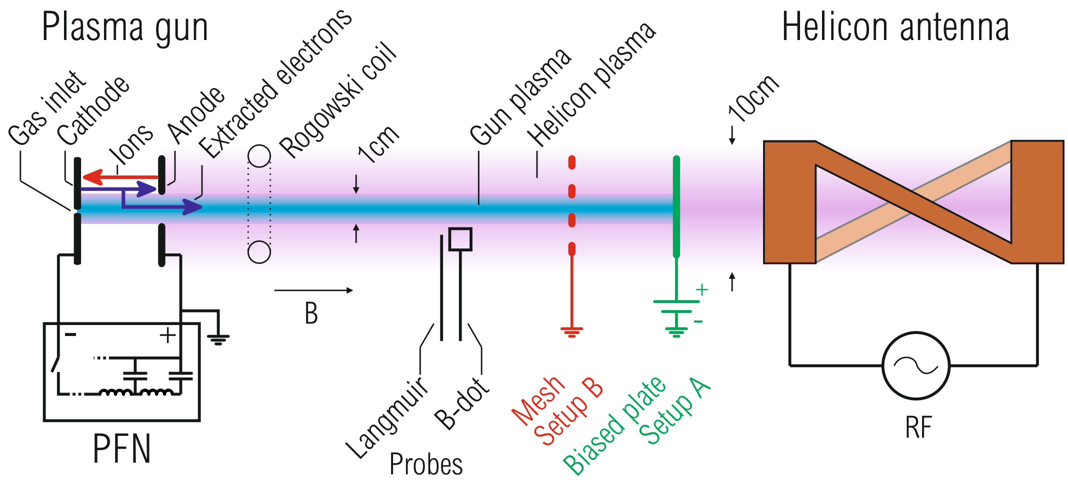

Figure 2: Plasma gun and accompanying experimental setup.

azimuthal cross section is shown in fig. 1b). Along the X-line, the resulting inductive electric field ($E_{||}$ =240 V/m in vacuum) can drive a high current in a narrow current sheet. In an open field line configuration as is present in VINETA II, the axial current is limited by sheaths at the end plates. Therefore, an efficient electron source is required to counteract the buildup of electrostatic fields, which would subsequently limit the reconnection rate to a low value imposed by boundary conditions. Two candidates for this sources are a hot cathode and a plasma gun.

The latter is used for the present paper and is shown schematically in fig. 2 (left). The gun creates a high current arc discharge in a confined volume between its cathode and anode. In order to enable the arc breakdown, a small amount of gas is puffed into the gun and a high voltage (U =2 kV) is subsequently applied. After ignition, thermal electron emission from the cathode provides a large current which is shaped to a nearly rectangular pulse by a pulse forming network (PFN). Thus, an arc discharge current of 800 A can be sustained for 60 μs.

The objective of VINETA II is to provide a self-consistent reconnection environment in which the external reconnection drive induces a current in the background plasma, which is supported by an electron source and which in turn modifies the in-plane field. However, before the full system is considered, it is crucial to be aware of the interaction of the current channel with the background plasma alone in order to avoid false attribution of observed phenomena to the reconnection process. Therefore, the plasma gun has been used to drive a current comparable to that expected for reconnection within a background plasma as shown in fig. 2. In setup A (components in green), a postively biased plate creates an electrostatic field which draws the gun current. Diagnostics include current monitors in the PFN (anode and cathode current) and in the plate bias circuitry, as well as a Rogowski coil in front of the gun muzzle. In setup B (components in red), an additional background helicon plasma is added, and the plate is

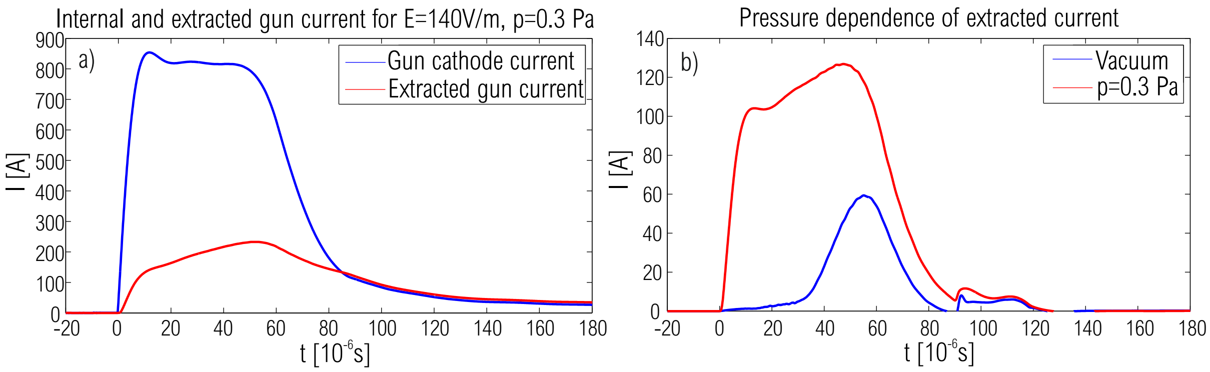

Figure 3: Time traces of plasma gun currents in setup A. a) Internal arc current (blue) and extracted current (red) with applied plate bias. b) Extracted gun current without (blue) and with (red) background pressure.

replaced by a grounded mesh which allows the two plasmas to interact. Further diagnostics include Langmuir probes which enable the characterization of the background plasma and a B-dot probe to identify electromagnetic fluctuations.

Fig. 3a) shows a time trace of the internal arc current (blue) and the extracted current (red) as recorded by the Rogowski coil. The cathode current is unaffected by external parameters such as the applied bias and solely follows the pulse shape set by the PFN. The extracted current can reach a significant proportion of the arc current ($I \approx$300A) and is shown here for a grid distance of 35 cm and bias of 50V, resulting in a static electric field of $E = 140\,\mathrm{V/m}$. An estimate of the current expected for the reconnection current sheet can be made using target plasma parameters of $n_e = 10^{16}\,\mathrm{m}^{-3}$ and $T_e = 6\,\mathrm{eV}$. Assuming Spitzer resisitivity, $j = E_{ind}/\eta_{sp} = 2.6 \cdot 10^6\,\mathrm{Am}^{-2}$ and $I_{gun} = j \cdot A_{gun}$ =265A, which the gun is able to produce.

The actual extracted current consists of high energy electrons directly emitted from the cathode as well as the electron saturation current from the plasma created by additional ionization. This can be seen in fig. 3b), where the gun is shot into a vacuum (blue) and into an argon gas background (p =0.3 Pa), respectively.

Inserting the gun into a helicon rf plasma (setup B with $n = 3 - 5 \cdot 10^{18} m^{-3}$, $T_e = 1.9 - 2.5\,\mathrm{eV}$) poses no problems regarding discharge stability, since the cathode is grounded up to the moment the high voltage is applied by a thyristor. On the contrary, preionization of the gas puff by the background plasma increases the reliability of discharge timing. Fig. 4a) shows that the extracted gun current is increased by 25-50%, where the current scales with density. Monitoring all involved currents shows that closure is given by subtracting the anode (dashes) from the cathode (dots) current, resulting in the values measured by the Rogowski coil (line).

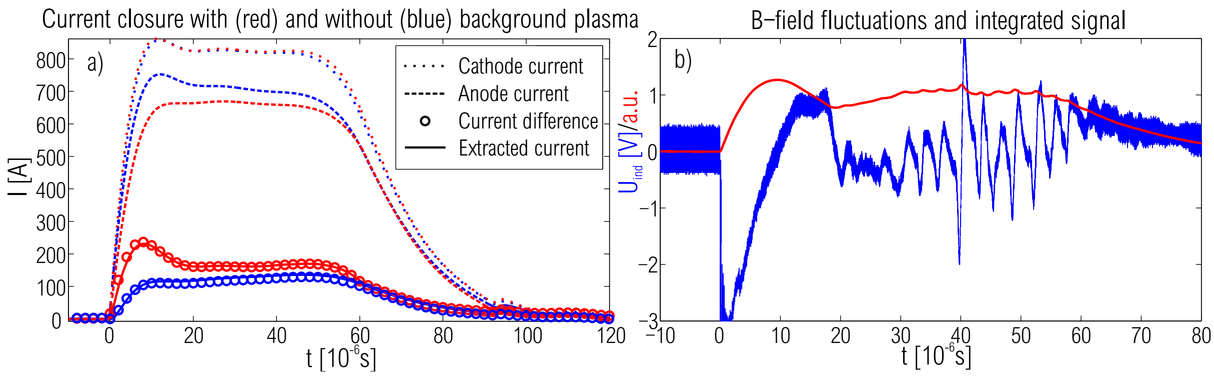

Figure 4: a) Time trace of gun currents in setup B for shots without (blue) and with (red) background plasma. b) Time trace of $\dot{B}$ probe signal (blue) and time-integrated values (red).

With background plasma, the cathode current doesn't change, whereas the anode current is reduced. This deficit is unlikely to stem from the plasma's ion current due to low ion mobility, however why the electron current to the anode is reduced in this case remains to be investigated.

Fig. 4b) shows magnetic field fluctuations which arise during the current plateau as measured with a B-dot probe, as well as the time-integrated signal for reference. The fluctuation amplitude is erratic and the signal incoherent. Changing external parameters such as the magnetic field, gas pressure, helicon plasma density or mesh distance does not affect its frequency ($f \approx 300$ kHz), though as a general tendency, a strong magnetic field increases the coherency, while lower gun arc currents delay the onset. This suggests that the fluctuations stem from the high-density plasma of the gun, which is difficult to modify due to the nature of the discharge. It remains to be investigated if the fluctuation is a propagating wave by correlation analysis of 2 probes, and if it is an internal effect of the gun or an actual interaction with the plasma volume.

In conclusion, the plasma gun reliably produces a current channel comparable to that required for reconnection in the VINETA II experiment and functions well in a plasma environment. Further investigations are required to clarify the reasons for electromagnetic fluctuations observed within the current channel and possibly suppress them.

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