FlareLab: Short time-scale diagnostics for rapidly moving magnetic flux tubes

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Experiment

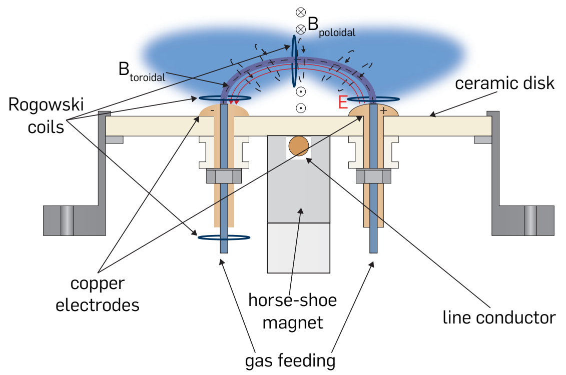
The FlareLab experiment is a pulsed-power discharge designed to study the behaviour of plasma-filled arch-shaped flux tubes. Thereby, the experiment tries to mimic the dynamical behaviour of Solar prominences. Presently, the experiment is based on a theoretical model by Titov and Démoulin [1] and in its first version on a scheme proposed and operated by P. Bellan et. al. [2].

The experimental set-up is shown in figure 1a. By means of a fast gas valve a small amount of gas is puffed into the chamber directly in front of the electrode system. The two gas clouds merge and produce an ignition condition according to Paschen's law. After a typical time delay of 1 ms to 6 ms the gas is ignited through a 1 kJ capacitor bank. The plasma ignition follows along an initially loop-shaped magnetic guiding field which forces the discharge into a semi-circular shape. This magnetic field is produced by a pulse forming network connected to a line conductor underneath the electrode plane. After ignition the plasma pinches along the magnetic axis. For a more detailed description of the experiment see [3] and [4].

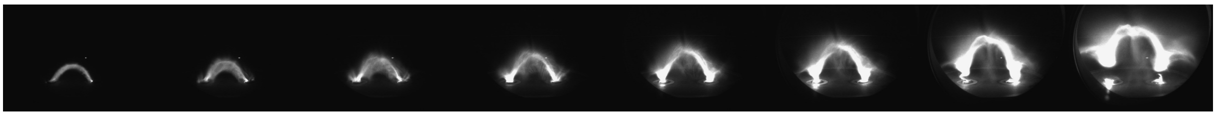
To illustrate the evolution of the discharge, images taken in subsequent shots by means of an intensified CCD camera are shown in figure 1b. During the first microsecond the arch collimates and then starts to expand into the vacuum chamber on a µs time-scale. Several µs after ignition the arch detaches from the electrode system and continues its expansion into the chamber. In figure 1b it can be seen that the apex height of the arch rises at a constant rate even after the detachment.

Diagnostics

As the FlareLab experiment is a single shot experiment operating on a µs time-scale, the development of diagnostics is challenging: Two intensified CCD cameras (a single-frame and an eight-frame camera) are operated at FlareLab to follow the evolution of the discharge. Additionally, miniaturized Rogowski coils are employed to measure the current within the plasma. Further, a CO_2 laser-interferometer [5], double- and triple-probes [6], and optical emission spectroscopy [4] are used to determine the electron density of the arch. Also magnetic induction



(a) Experimental realization of the Titov-Démoulin model



(b) Evolution of the arch

Figure 1: Experimental set-up, diagnostics set-up in the chamber & flare evolution

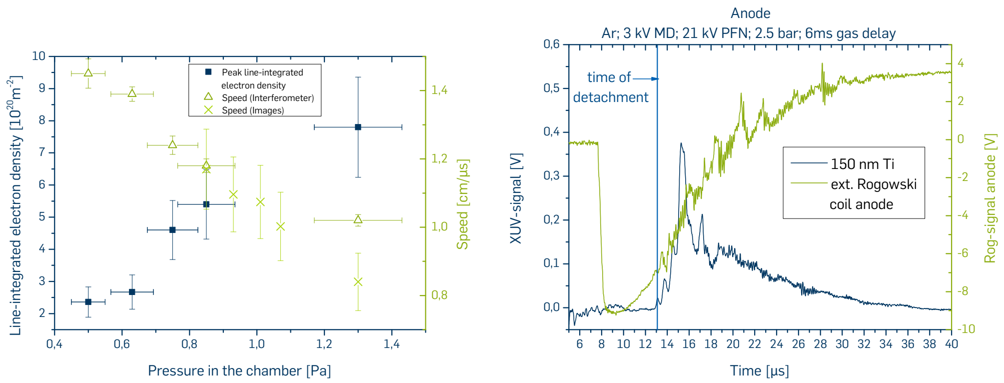
probes [4] and an XUV-detector are operated at the experiment. As the discharge is very reproducible from shot to shot, temporally- and spatially-resolved measurements can be obtained by successive shots and altering the position of the diagnostics on a linear stage inside the vacuum chamber in between the shots.

The CO_2 laser-interferometer is a classical Michelson set-up whose probing arm is inside the vacuum chamber. The probing beam is perpendicularly aligned to the image plane from figure 1b and through the apex. The line-integrated electron densities can be determined from the phase shift $\Delta\varphi = r_e\lambda \int_0^L n_e(l)\, dl$ caused by the plasma, where r_e is the classical electron radius, λ the wavelength of the probing beam and $n_e(l)$ the electron density along the line-of-sight L. For more detailed information on the analysis of the interferometric data see [5]. The measurements were conducted in the apex of the arch with different discharge parameters and were compared to triple-probe [6] and Stark broadening measurements conducted in the vicinity of the foot points of the discharge. Spectroscopic and interferometric measurements agree reasonably well within the limitation of comparing line-integrated and local densities.
Most recently, the influence of the amount of the injected gas into the chamber was measured by means of the interferometer to evaluate the mass density dependency on the evolution of the arch. Those measurements are shown in figure 2a, where the peak line-integrated electron density and the expansion speeds are plotted against the injected gas amount. The peak line-integrated electron density is obtained by evaluation of a whole series of shots with the same gas-pressure and taking the absolute maximum value for the distinct gas-pressure. To obtain

expansion speeds, the point in time where the line-integrated electron density has its maximum for each shot is taken and plotted against the distance of the laser beam from the electrodes. As the expansion of the height of the arch is constant, a linear fit can be applied to the data points. For comparison the expansion speed is also determined from sequences of CCD images. On the one hand it is obvious that the electron density increases with the injected amount of gas into the chamber, but on the other hand the speed of the height of the arch decreases with increasing amount of gas. Earlier investigations[3] showed that a variation of the gas type and thereby the plasma mass did not influence the evolution of the arch by the same amount. Further work will include measurements with different gas types and a modified set-up to measure the line-integrated electron density in the foot-points of the discharge.

As can be seen in the pictures (c.f. fig. 1b), the arch detaches from the electrode system in a very reproducible way at 3 µs to 7 µs after ignition. The detachment depends on the amount of gas injected and also the voltage applied to the electrode system – the higher the gas amount or voltage, the earlier the arch detaches. This phenomenon is still under investigation: Miniaturized Rogowski coils in the chamber directly measuring the current flowing through the plasma were applied in the apex and at the foot points where the detachment occurs. A discrepancy of about 30 % between the current supplied by the capacitor bank and the current flowing through the apex or the foot point region can be observed. I. e., the current through the Rogowski coil at the point of ignition of the arch saturates at approx. 6 kA when the arch detaches from the electrodes, while the current provided by the capacitors continues to rise. With increasing distance of the Rogowski coil from the electrode plane the current in the apex even decreases. Similar observations have been stated in [7], where also only a tenth of the applied current is assumed to flow through the arch.

A very analogous behaviour is observed near the electrode region: Directly in front of the electrodes almost the entire external current flows through the Rogowski coil but with increasing distance of the coil to the electrode the current drops to about thirty percent of the current supplied by the capacitor bank. In parallel, an XUV diode has recently been applied at the bottom end of the chamber with a direct line-of-sight on the electrode region. The XUV-diode is mounted on a two-dimensional linear stage and the line-of-sight is restricted by a pinhole which allows for spatially-resolved measurements of the electrode region. Incoming charged particles are deflected by a magnetic trap in front of the pinhole. The energy of the photons can be filtered by utilising different foils in front of the XUV-diode which restricts the energy of the observed photons to a threshold energy of 15 eV. Figure 2b shows next to the XUV-signal (line-of-sight is on the anode – in black) the raw signal of the Rogowski coil applied to the external feed-



(a) Peak line-integrated electron density and corresponding speeds for different gas-pressures

(b) XUV-diode signal from the back-end of the chamber and Rogowski raw data of the externally applied current

Figure 2: Current measurement in the apex and XUV measurement with line-of-sight on the anode

ings from the capacitor bank (red). After detachment it can be observed that the current starts oscillating and also the XUV-diode follows those oscillations.

Conclusion

Numerous diagnostics have been developed to study the behaviour of the pulsed-power discharge in the FlareLab experiment. The results suggest that the luminous structure in the CCD images is indeed the region of high plasma and current density. Furthermore, oscillations in the plasma current can be correlated to the generation of XUV photons (>15 eV), whereas the generation mechanism is still topic of investigation.

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