THE PRAGUE FAST CAPILLARY DISCHARGE: PRELIMINARY RESULTS

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1. Introduction

Two different experimental approaches to the pulsed capillary discharges as potential sources of soft X-ray radiation are followed at present: the historically older one (it dates since mid sixties) is to study the discharges in evacuated capillaries initiated by a surface breakdown along the capillary wall [1, 2]. In spite of the fact that such a breakdown does not ensure well defined initial conditions (the discharge is hardly homogeneous and the number of evaporated particles is uncontrolled), the amplification of stimulated emission (following plasma recombination pumping scheme into hydrogenic ions) has been observed at several experiments. The gain and the anomalous line intensity ratios, though weakly dependent on the discharge length, are reported e.g. in [3, 4]. The second approach was initiated by Rocca et al. in 1993. The pronounced amplification in a gas-filled-capillary discharge (due to collisional excitation pumping scheme) reported in his pioneering work [5] is provided by using massive pre-ionisation and a fast current rise-time. In this way the amount of the material ablated from the walls and, hence, the number of particles to be heated, is limited by a rapid detachment of plasma from the capillary walls (by Z-pinch effect). In next few years the Rocca's group reported [6, 7] demonstration of lasing and achievement of saturation limit on neon-like argon (Ar IX) line {3p-3s transition, $\lambda = 46.88$ nm}. These results triggered a burst of interest and a number of papers appears and specialized sections in conferences are organized.

Even we were attracted by numerous applications of coherent soft X-rays and decided to build (following the second approach) a fast capillary discharge, despite it is generally understood as a relatively sophisticated apparatus. Since the beginning we paid great attention to its design: we performed a lot of modelling and optimisation [8, 9]. The present paper aims at comparison the designed (computed) parameters with the values measured by a combined capacitance-resistance voltage divider and Rogowski coils. Finally we report the first time-integrated visible spectra of the discharge flashing through the argon-filled capillary.

2. Apparatus

The designed apparatus (see Fig. 1) consists of a Marx generator, a coupling section (spacer), a fast capacitor (pulse forming line) with a closely coupled main spark gap and a capillary.
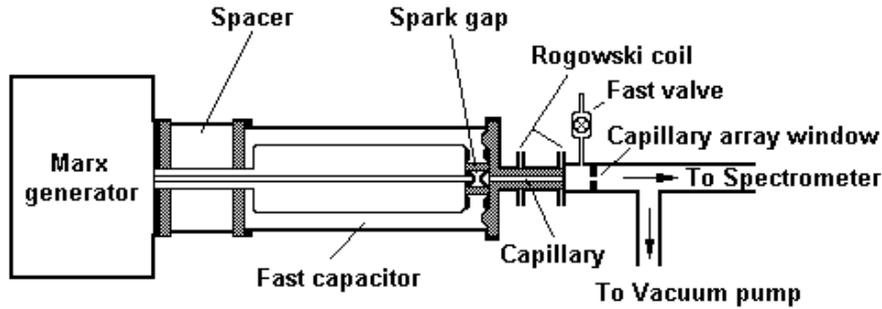
Fig. 1. Schematic drawing of the apparatus.

The gas filling and pumping assembly is attached to the outer end of the capillary.

The 8-stage fully-screened oil-insulated Marx generator (originally used at REBEX machine) has erected capacity 12.5 nF and erected voltage up to 400 kV.

The coupling section (spacer) is a short SF_6-gas-filled coaxial cylindrical line, which functions as an interface between the oil-insulated Marx generator and the water-filled pulse forming line.

As a fast capacitor we use a coaxial cylindrical line with de-ionised water as a dielectric. It has capacitance $C_{line} = 6.01$ nF, and characteristic impedance $Z_{line} = 3.37\ \Omega$. At the end of the line the main spark gap (filled by SF_6 gas) is placed, to which a capillary assembly is attached.

The 20 cm long capillary (made of alkaline polyamide) is directly attached to the main spark gap (having one common electrode). It is placed in a shielding and circuit closing metallic cylinder of the diameter of 60 mm. The working gas is injected as well as the generated radiation is monitored through orifices in the outer electrode.

Such a design is very critical: on one hand the fast current rise-time requires to diminish both the capacitance of the fast capacitor and the inductance of the circuit (and, therefore, the circuit dimensions) as much as possible, on the other hand it is necessary to have a sufficient amount of energy for ionisation of the gas atoms up to their K-shell. It means to increase the voltage and to scale up the insulators accordingly.

In order to test the design, the Laplace-Poisson equation in the most exposed regions was solved (see [8, 9]). This helped us to determine not only the minimum save dimensions of insulators and the optimum roundness of the conductor edges but also the mutual capacitance of individual components.

3. Modelling and comparison with the experiment

For model calculations an equivalent circuit was constructed (see in more detail [10]), in which both the measured and the calculated values were substituted. The fast capacitor is

modelled as a line with distributed parameters having 10 identical elements. The transient characteristic of this circuit is solved first, till the voltage on the spark gap reaches its breakdown value (see Fig. 2). Then the solution continues with the changed circuit (see Fig. 4, 5). The erected voltage of the Marx generator was $U_O = 160$ kV in all cases. It turned out that charging of the fast capacitor takes ~800 ns (Fig. 2) and during this time the line voltage (measured by combined capacitance -resistance divider) rises up to ~ 130 kV. Fig. 3 shows the capillary current (having the amplitude ~ 100 A) as measured by a Rogowski coil as long as the pressure-distance product is higher than its breakdown value in the main spark-gap. In the moment of the main spark gap breakdown (t = 0) the capillary voltage rises steeply and then oscillates with a reasonable damping (see Fig. 4). The current-rise is as fast as 1.3×10^{12} A/s and the current amplitude reaches ~20 kA (Fig. 5).

**Voltage in the middle of the line**
prior to breakdown
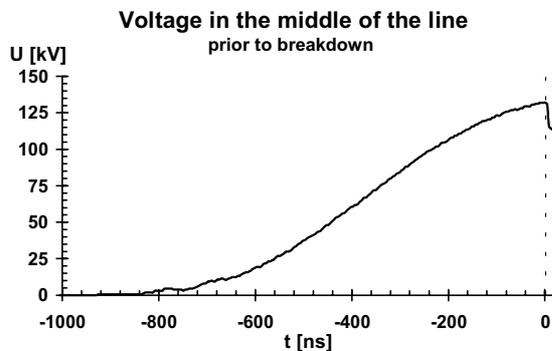
Fig. 2. Measured voltage in the middle of the line prior to breakdown

Capillary current
without breakdown
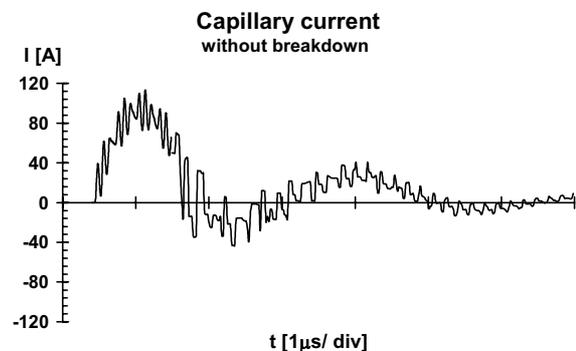
Fig. 3. Measured capillary pre-breakdown current
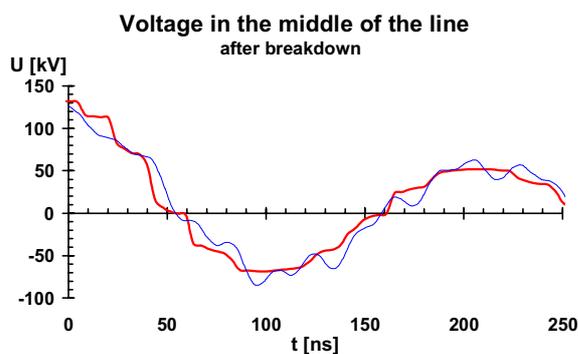
Voltage in the middle of the line
after breakdown

Fig. 4. Voltage in the middle of the line after breakdown: red bold line - measured curve, blue thin line - result of simulation

Capillary current
after breakdown
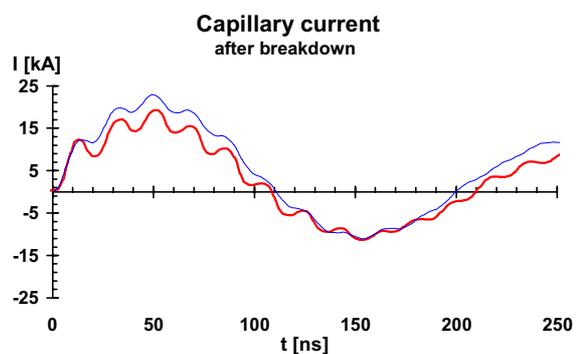
Fig. 5. Capillary current after breakdown: red bold line - measured curve, blue thin line - result of simulation

4. Spectroscopic measurements

The first time-integrated visible spectra were taken in the axial direction of the argon filled (filling pressure ~200-400 Pa) capillary with the help of imaging spectrograph Chromex 500 IS equipped with intensified CCD readout (Tektronix 1024x1024 back illuminated chip). The

whole survey visible spectrum was taken on shot-to-shot basis and the intensity calibration was made by tungsten ribbon lamp. Due to the long exposure (30 ms) the spectrum is influenced mainly by the afterglow plasma. Therefore, in the spectrum dominate Balmer alpha and beta lines of hydrogen relieved probably of the capillary walls after plasma expansion. Both of these lines are split - the first one exclusively due to self-absorption, the second one even due to its nature (the absence of the central Stark component). A preliminary analysis of the Balmer alpha and beta line-profiles yields an averaged density of afterglow plasma 10^{17} cm^{-3} and average temperature ~0.5 eV. Together with many argon lines we found also some lines of oxygen and carbon (which elements are probably also of the capillary-wall origin).

5. Conclusion

First, it was shown that results of combination of a simple electrostatic field mapping (which on one hand warns against local voltage overloading, on the other hand it enables to calculate mutual capacities of individual components) and a classical equivalent circuit analysis gives an excellent agreement with measured curves and, therefore, its use at the design of future devices is strongly recommended.

Second, our test shots with the half charging voltage (160 kV) demonstrated that our driver has very similar electrical parameters as the apparatus at the Colorado State University, where saturated stimulated emission in Ne-like Ar line has been demonstrated [7].

Acknowledgement

References

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