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Refined design of a new driver for fast capillary discharge

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Abstract A new driver of the fast capillary discharge has been designed. It consists of the Marx generator and radial Blumline pulse forming line. Such a geometry enables axial access to both capillary ends ("transparent capillary"). This arrangement substantially simplifies the experiments (adjustment, monitoring, applications). The designed apparatus is capable of reaching the discharge current of the order of 120 kA and the discharge current rise time 2.9×10^{12} A/s, which is sufficient for the investigation of amplification in non-traditional electronic transitions.

Key words fast capillary discharge • soft X-ray laser

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Introduction

Probably one of the most challenging features of high current pulse capillary discharges is a possibility to work as a soft X-ray laser. There are two main ways to the population inversion in capillary discharges: an electron-collisional recombination pumping scheme and an electron-collisional excitation pumping scheme.

The excitation pumping scheme usually uses neon – or nickel-like ions the upper laser level of which is populated by electron collisions. This may be achieved in gas filled capillaries of the diameter ~3–6 mm by a fast current rise – as high as ~1–4.10^{12} A/s in a pre-ionised gas, which ensures a rapid detachment from the capillary walls (by Z-pinch effect). In this way the amount of material ablated from the walls is kept small and a limited number of particles is heated [4]. However, the capillary with a pre-ionised gas must be isolated from the charging capacitor by a spark-gap – for symmetry reasons usually mounted on the capillary axis in the vicinity of the capillary high-voltage electrode [4, 5]. Such an arrangement prevents efficient gas filling of the capillary, and disables the apparatus from proper aiming of the capillary radiation at a measuring equipment (detector, spectrograph, streak camera) or at a target. Also a simultaneous radiation application and its monitoring as well as an effective doubling of the capillary length by using a multilayer mirror is in this arrangement very difficult. This all can be avoided with a "transparent" capillary (with free radiation escape from both its ends) fed by the radial Blumline pulse forming line [1]. The optimized design of such a geometry is the subject of this paper. For this we used an equivalent circuit analysis, similar to that we used for the design of our previous driver [3]. However, even this concept has some technical disadvantages: the double-stage radial pulse forming line must be

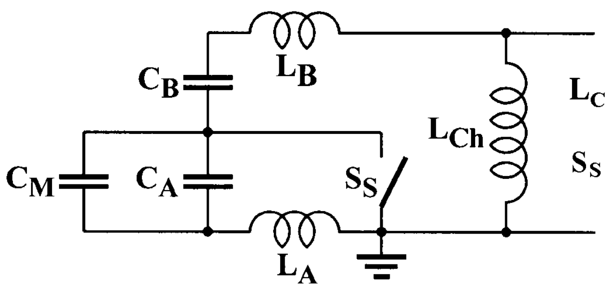

Fig. 1. Principal scheme.

switched at its outer radius – from symmetry reasons in more than one (the more the better) azimuths. Simultaneous "multichannel" triggering requires triggered spark gaps with minimum jitter, i.e. the elements whose successful construction needs a thorough background in the field of pulse power technology. In our recent conference contribution [2], we have already published such a design. However, there, the main insulator had a relatively large diameter (1220 mm – hence, it would be rather costly) and a little attention has been paid to the dielectric strength of the construction. Therefore, in the present paper we publish a modified design in which the outer diameter of the main insulator is reduced to one half (610 mm) and the electric field strength of the critical places is thoroughly investigated. The optimisation of the electrical circuit requires the capacity of the pulse forming line to be approximately the same as the capacity of the erected Marx generator. Therefore, even the water filled gap of the pulse forming line had been reduced (from 125 mm down to 40 mm).

Apparatus

The designed apparatus – a principal scheme of which is given in Fig. 1 and the top view is presented in Fig. 2 – consists of a feeding Marx generator C_M, which charges both sections of the radial double water line (Blumline) C_A and C_B. As soon as the charge of the erected Marx generator pours over to the central electrode of the radial double water line (common electrode of condensers C_A and C_B), while both outer electrodes are kept near zero potential (by construction inductances L_A and L_B and by charging inductance L_{Ch}), the set of spark-gaps S_S (located at the outer radius of section "A") are fired generating nearly doubled output voltage on the capillary (load L_C) placed in the axis – i.e. in the inner ends of this pulse forming line. Capillary breakdown is represented by the turning on the switch S_C.

Modelling

At the given Marx generator erected capacity (6 nF) and Marx generator maximum erected voltage (800 kV), the modelling should help us to optimise the outer radius r_e of the pulse forming line (supposing that its inner radius r_i is determined by the possibilities of the construction) and the spacing h of the electrodes arriving so at the maximum capillary current with the highest achievable current rise time. The equivalent circuit of the set up is shown in Fig. 3.

Firstly, such a 'pulse forming line' outer radius r_e and such an electrode separation h are searched to attain a maximum charge in the middle (charging) electrode of the pulse forming line (i.e. minimum residuum charge on the Marx generator). For this reason, it was sufficient to solve the transient characteristics of the equivalent circuit with all the switches in off-position. Such an optimisation yields two sets of curves (see [2]) – the first showing the maximum permissible voltage of the Marx generator (which depends not only on h, but due to the voltage overswing – different for different capacitances – also on r_e), the second indicating the minimum residuum voltage of the Marx generator.

Secondly, the capillary voltage and the capillary pre-breakdown current is maximised by an appropriate choice of the charging inductance L_{Ch} and/or charging resistance R_{Ch} (which control the charging delay of the section B behind the section A) and by a suitable switching time of the spark gaps S_S (see Fig. 4) .In this case we suppose that the capillary does not breakdown (switch S_C in off-position). It is visible that at the present choice of L_{Ch} = 690 nH, the capillary voltage is as high as 1.5 times the Marx generator voltage and that its maximum is in certain small interval relatively flat (see envelope of the curves, Fig. 4, bottom) yielding some space for choosing the optimum pre-breakdown current. Of course, the final optimisation must be done experimentally, determining which pre-breakdown current is sufficient for the development of the main discharge.

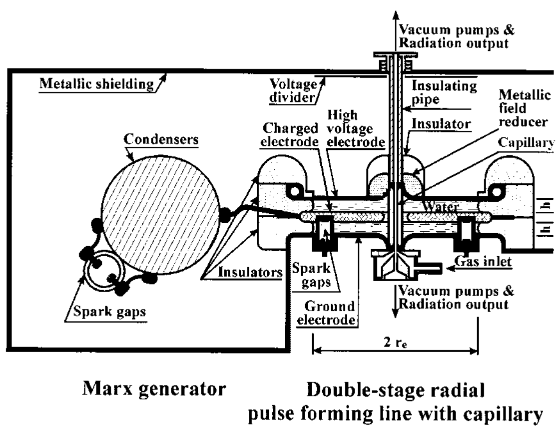

Fig. 2. Apparatus – top view.

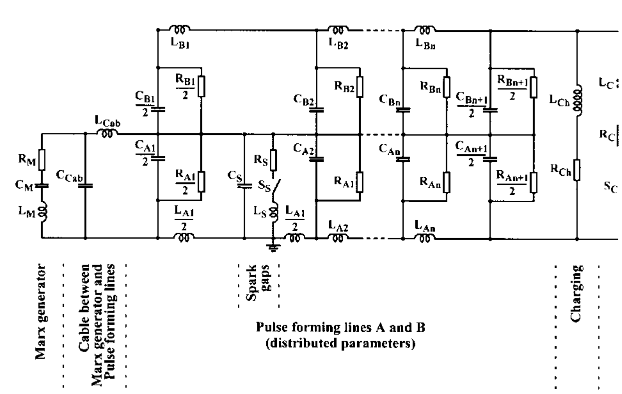

Fig. 3. The equivalent circuit of the set up.

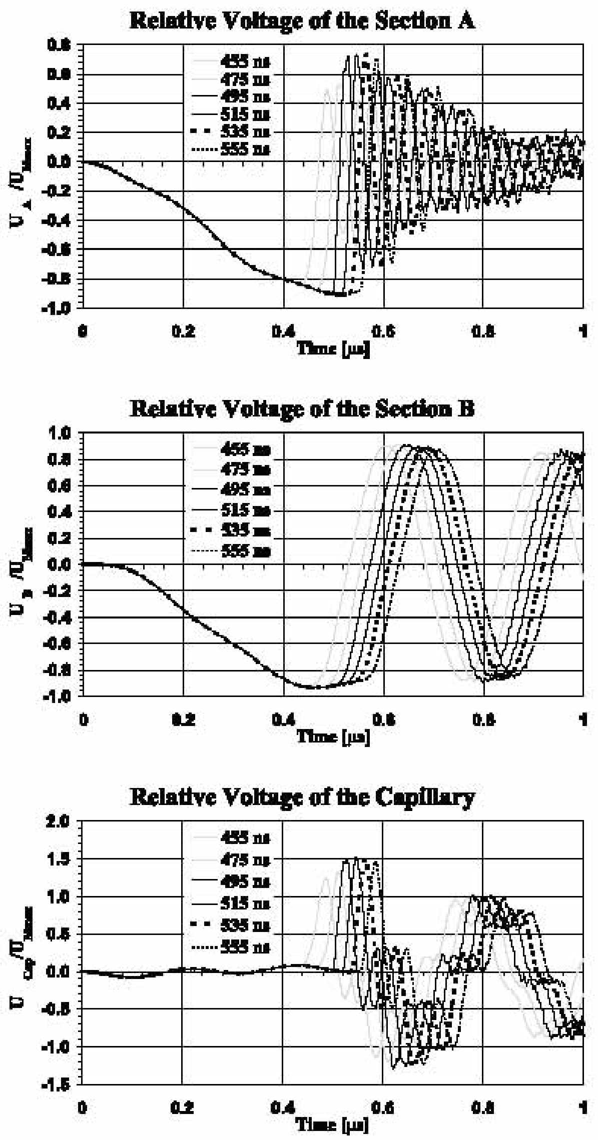

Fig. 4. Switching time optimisation: relative voltages on individual sections and the capillary relative voltage (non-conducting capillary).

Thirdly, for the selected parameters the capillary current and the capillary current rise time are checked. It turns out that for this set of parameters the capillary current is as high as 15 kA per 100 kV of the Marx generator voltage (see Fig. 5). Therefore, the current amplitude 36 kA currently available in our present driver with the coaxial pulse forming line is reached in the designed driver at the Marx generator voltage 240 kV. Hence, at the Marx generator maximum voltage 800 kV the current amplitude ~120 kA is expected, which promise a possibility to investigate an amplification of a "new" electronic transitions. The current rise-time is as high as 3.6×10^{11} A/s per 100 kV of the Marx generator voltage – i.e. $\sim1.1\times10^{12}$ A/s at our currently used charging of 300 kV (comparable with our present current rise time) and 2.9×10^{12} A/s at the charging of 800 kV. Such current rise

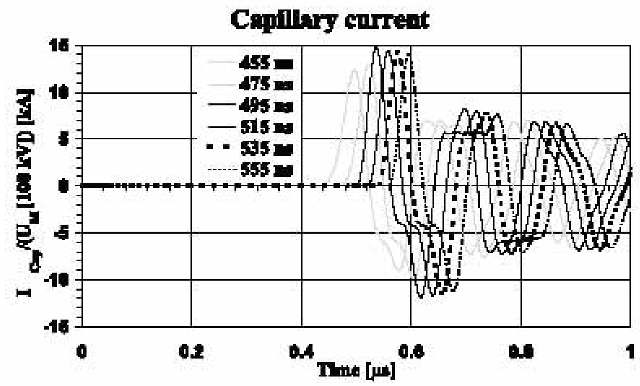

Fig. 5. Switching time optimisation: capillary current.

time in combination with suitable choice of the capillary wall material should ensure a fast plasma detachment from capillary walls and heating a limited number of particles of the filling gas only.

Conclusions

The new "transparent capillary" driver was designed (both capillary ends accessible) capable of reaching the discharge current as high as 120 kA and the discharge current rise time 2.9×10^{12} A/s. This should substantially simplify the experiments (adjustment, monitoring, application) and it should be able to draw higher currents with higher current rise time through the capillary enabling the investigation of amplification in non-traditional electronic transitions.

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