

Investigation of Metal Puff Z pinch Based on Multichannel Vacuum Arcs

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Abstract. The performance of a metal double puff Z-pinch system has been studied experimentally. In this type of system, the outer and inner cylindrical shells were produced by ten plasma guns. Each gun initiates a vacuum arc operating between aluminum electrodes. The net current of the guns was 80 kA. The arc-produced plasma shells were compressed by using a 450-kA, 450-ns driver, and as a result, a plasma column 0.2 cm in diameter was formed. The power of the Al K-line radiation emitted by the plasma for 7 ns was 800 MW/cm.

1. Introduction

The processes that occur in imploding Z-pinchs are currently studied by using both terawatt machines and university facilities capable of producing pulse powers of tens of gigawatts [1-5]. The Z-pinch experiments carried out on terawatt setups are aimed at optimizing the conditions for soft X-ray production or at realizing controlled thermonuclear fusion [1,6,7]. These experiments are very time-consuming and expensive. At the same time, as validly mentioned by the authors of Ref. [2], the small university setups, allowing low-cost experimentation, are well suited for testing both new diagnostics and new schemes for realization of proper initial conditions in imploding plasma shells in Z-pinch experiments. In the paper we demonstrate to use for small setups an annular plasma jet (plasma metal puff) which is generated by a vacuum arc discharge (VAD).

2. Experimental results

The diagram (Fig.1) presents a sketch of a metal puff Z-pinch. IMRI-5 [8-10] linear-transformer-driver (3.2 μ F, 70 kV) was a driver for the Z-pinch. IMRI 5 has the current of 450 kA and the rise-time of 450 ns. The IMRI 5 current flows through the metal plasma cylinder from the high-voltage electrode to the ground electrode. Ten plasma guns are arranged around a central electrode. The central electrode is the common anode for all plasma guns. The ten arc discharges are powered by a common capacitor bank of capacitance 20 μ F charged to a voltage $U_{\text{gun}} = 20 - 25$ kV. To sync the IMRI-5 generator to the capacitor bank, a delay generator is used. The time delay between the operation of IMRI-5 and the onset of current in the guns, t_{del} , was varied from 1 to 11 μ s. The arcs burn between the rod cathodes and the anode inside a small cavity and the arc plasma spread about the narrow slot. The cathodes and the anode are manufactured from the same metal. Generated plasma



flows through the slot between two cylinders and it forms an annular shell. We worked with Al and Mg single and double puffs. We used a Mo plate as a ground electrode that permits to carry out the experiment without disassembling the vacuum chamber after every shot. In this experiment, the net gun current, the pinch current (IMRI-5 current), and the characteristics of the Mg K-line radiation emitted by the pinch were measured. To measure the K-line radiation power, a Diamond Radiation Detector (DRD) filtered with 18- μm thick polypropylene film was used.

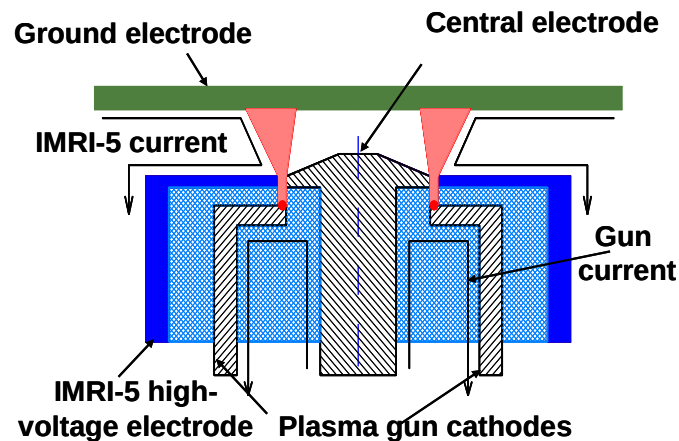


Figure 1. Schematic diagram of the metal puff Z-pinch system. Mo plate with a 10-mm dia hole at the centre is the ground electrode.

The performance of a single metal puff was presented in Ref. [8]. The performance of a double metal puff is described in the paper. Double metal puff consists of two plasma metal shells- outer and inner. For double metal puff we used the same hardware as for single metal puff. But at this case the gun current has another path. First, the gun current flows along the gun electrodes; after that it flows through the arcs that produce both the outer shell and inner shell. Thus, the arcs of the inner and outer shells connect in series.

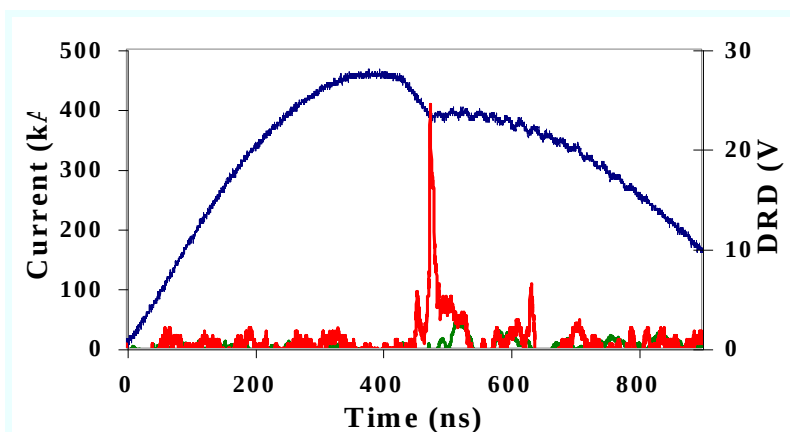


Figure 2. Waveforms of the current and DRD signal for a double metal puff.

Fig.2 shows the current and DRD waveforms for a double Al metal puff. For this shot D_{out} and D_{in} = 40 mm and 8 mm respectively. The current waveform has a pronounced dip and it permits us to

estimate the energy delivered to load. For this shot K shell energy and power are 30 J and 8 GW respectively, FWHM = 7 ns, total input energy is 980 J. Pinhole picture showed the stable plasma column with diameter of 3 mm. Hence, the implosion ratio is equal to 12 approximately.

Fig.3 shows the dependences of K-shell power and energy vs t_{del} for Al double puffs. We carried out the experiments with two different inner shell diameters: 10 and 15 mm. The outer diameter was equal to 40 mm for both sets. Both the power and energy are more for the inner diameter of 10 mm. We had the similar implosion time for both modes: something about 500 ns at the time delay of 4 μ s. But the K-shell pulse duration is different: 7 ns for diameter of 10 mm and 15 – 20 ns for diameter of 15 mm.

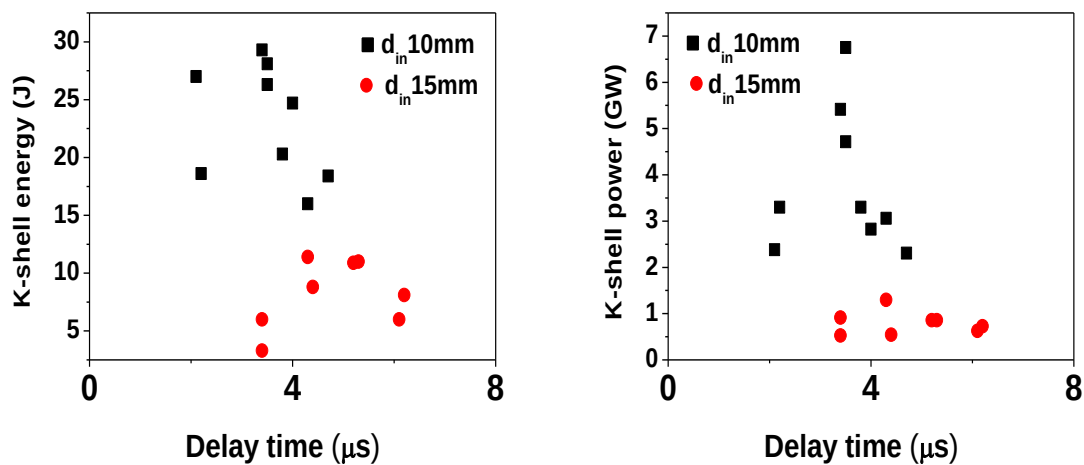


Figure 3. The K-shell energy and power versus the delay time t_{del} between the onset of the current I_{gun} and the onset of the IMRI-5 generator current I_{pinch} .

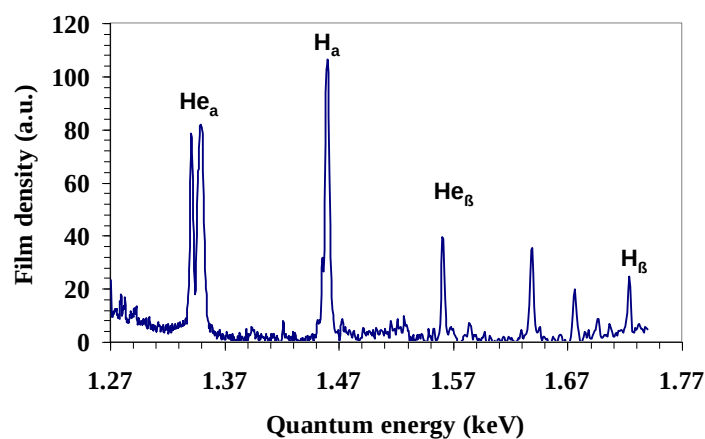


Figure 4. Mg double puff spectral measurements.

We carried out also the experiments with Mg double puff Z-pinch. In whole, the Mg double puff data are similar to those for Al. For the Mg double puff shot K shell energy and power are 80 J and 7 GW respectively, FWHM = 17 ns. In several shots with Mg double puffs, spectral

measurements were performed and the line intensity ratio has been found for the hydrogenlike and heliumlike magnesium ions, $I_{H\alpha}/I_{He\alpha}$ (see Fig.4). Knowing this ratio, we can determine the electron temperature T_e and the ion concentration N_i for the hottest part of the imploded plasma column. We have calculated the values of T_e and N_i with the help of a collision-radiation equilibrium [11] using the values of $I_{H\alpha}/I_{He\alpha} = 2$ and K-line radiation power P_K . Thus, we have obtained $T_e \approx 900$ eV and $N_i \approx 1 \cdot 10^{18} \text{ cm}^{-3}$.

3. Discussion and conclusion

In this paragraph we compare our results with predictions of the Mosher, Krishnan and Qi model [12]. The authors of Ref.4 plotted a dependence K-shell yield Y_k as a function of ratio kinetic energy to the break energy W_{break} . In our experiment with double metal puff (450 kA, 450 ns) Al K-shell yield is 28 J/cm; kinetic energy estimated according to Ref.[1] at tenfold compression

$$W_{\text{kin}} = \frac{\mu}{4 \cdot \pi} \cdot I^2 \cdot \ln \frac{R_0}{R_{\text{fin}}} = 2300 \cdot I_{\text{pinch}}^2 \quad (1)$$

where R_0 and R_{fin} are the original and final radii of the Z-pinch. For Al I_{pinch} is equal to 450 kA; W_{break} is equal to 6.4 kJ and $W_{\text{kin}}/W_{\text{break}} = 0.465/6.4 \approx 0.072$. Thus, for our experimental data $Y_{k(\text{max})}/W_{\text{kin}} = 0.06$. According to the model estimates of Ref.[4], $Y_{k(\text{max})}/W_{\text{kin}} = 0.05$. Hence, our experimental data are a little above the estimates of the Ref.[12].

It is possible to see that our data are described by the same dependencies that the common Z-pinch loads as the wire-arrays and the gas puffs. Metal puff loads offer the possibility to produce the initial plasma shell for materials which are now not available in the form of thin wires, such as Be and Bi. A metal puff load is a completely ionized plasma shell, where the processes that may result in RT instability in the imploding shell are depressed. Also note that a metal puff experiment can be performed without disassembling the vacuum chamber after every shot, and this reduces the experiment duration. Thus, the metal puffs open new possibility for Z-pinch study.

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5. References

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