J. Plasma Fusion Res. SERIES, Vol. 8 (2009)

Gas-Puff Design and Hot Spot Formation in a Z-Pinch Plasma

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(Received: 31 August 2008 / Accepted: 6 December 2008)

The change of hot spot distribution and x-ray radiation were examined in a gas-puff z-pinch device by changing the shape of gas nozzle. It was confirmed that high temperature plasma and intense x-ray emission were obtained by reducing the flux of the gas. And also it was confirmed that long-wavelength instability developed by reducing the gas speed, and both input energy and x-ray radiation increased.

Keywords: gas-puff z-pinch, gas nozzle, hot spot, Rayleigh-Taylor instability, energy transfer, x-ray radiation, x-ray spectroscopy.

1. Introduction

Gas-puff z-pinch is a system in which the plasma is compressed and heated by the self-magnetic pressure produced by high current through the plasma, and high-temperature and high-density points (hot spots) are produced in this process [1,2]. The hot spots would be the strong source of EUV to soft x-ray range of light.

It has been understood in the process of gas-puff z-pinch research that the hot spot formation is strongly influenced by the gas distribution between the electrodes. The hot spots are produced as a result of MHD instability which is triggered by Rayleigh-Taylor instability developed during the shrinkage of the z-pinch. The spatial distribution of hot spots has strong correlation with the spatial pattern of the Rayleigh-Taylor (RT) instability [3]. Finite Larmor radius effect and viscosity are thought as the stabilizing factors of the RT instability. As those factors are effective at large wave number, the RT instability grows at a certain wave number or wavelength. If the latter factor is important, the initial gas distribution determines the wavelength of the RT instability, hence the location of the hot spots.

In this experiment, initial gas distribution was controlled by changing the shape of gas nozzle, and its influences on the hot spot formation and x-ray radiation were examined. And the electron temperature of the pinched plasma was evaluated from x-ray spectroscopy.

2. Experimental Setup

The experiment was conducted on the SHOTGUN z-pinch device at Nihon University. The schematic diagram of the device is shown in Fig. 1. The energy storage section of the device consists of 30 kV 24 μF capacitor bank, and the maximum discharge current is 300 kA. The charged voltage of the bank was 25 kV (7.5 kJ) in this experiment.

The center conductor of the device is anode, and supersonic gas is ejected by a high-speed gas valve through annular Laval nozzle mounted on the anode. Figure 2 shows a drawing of the gas nozzle. Gas is transmitted though many holes on the nozzle support, and then passes through the neck of the nozzle. The diameters of the transmitting holes were 2 and 3 mm, and the spacing of the neck was 0.4 - 0.7 mm. The distance between the electrodes was 3cm. Ar gas was used in this experiment, and the plenum pressure of the gas valve was 5 atm.

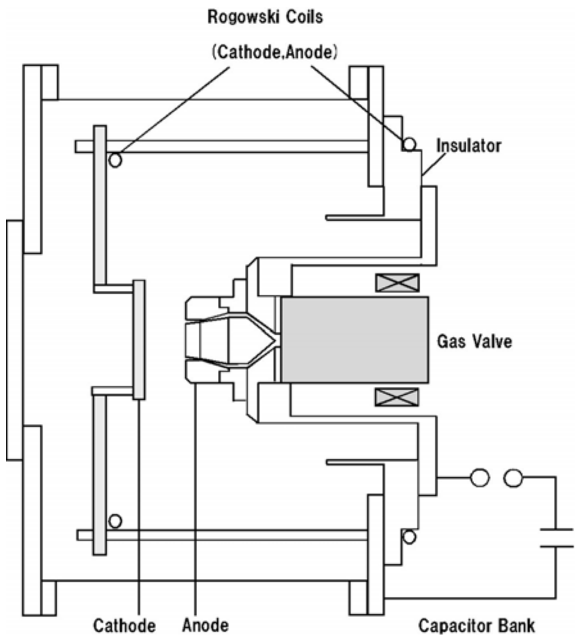

Fig.1 Schematic diagram of the SHOTGUN z-pinch device.

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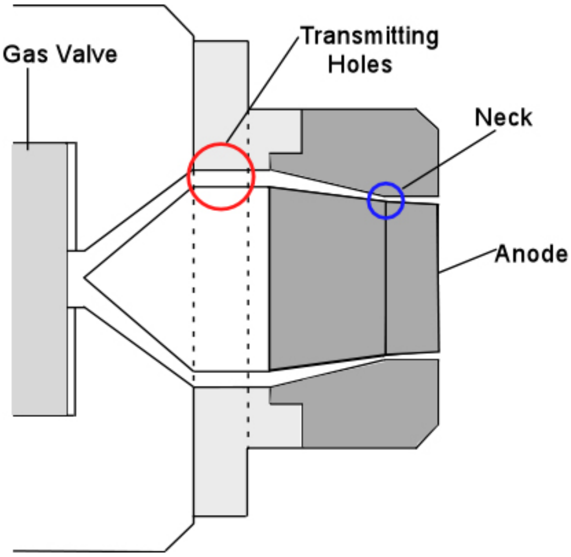

Fig.2 Gas nozzle for the z-pinch experiment.

Total discharge current was measured by an anode Rogowski coil located outside chamber, and the current between the electrodes was measured by a cathode Rogowski coil. X-ray signal was detected by a scintillation probe (SCI) with a 10 μm Be filter. An x-ray pinhole camera was used for taking x-ray image of the pinch plasma. A 10 μm Be filter was installed in the pinhole camera to prevent visible and ultraviolet lights. Kodak BioMax MS film was used for recording soft x-rays.

A Johansson type crystal spectrograph was used for the measurement of x-ray spectra of the plasma. Quartz crystal, whose lattice constant is 2d=6.68 A, was used. BioMax MS film was also used for recording x-ray spectra.

3. Discharge Current and Energy Transfer

Discharge currents and SCI signals of the experiment are shown in Fig. 3. The neck spacing is (a) 0.4 mm and (b) 0.6 mm, and in both cases the hole diameter is 3 mm. The delay time of discharge from gas-puff is fixed to 0.37 ms.

Both current begin to decrease at the time 1.2 μs and form dip. The discharge currents just before the pinch are (a) about 170 kA and (b) about 200 kA. The current in (b) rises more rapidly than in (a). The formation of the current dip is ascribed to the increment of circuit inductance due to the shrinkage of the plasma. X-ray emission is seen simultaneously. The SCI signal in the case (b) is more intense than that in (a). In the case (b), the cathode current is equal to the anode current up to the pinch time. But in the case (a), the cathode current begins to separate from the anode current at the time 0.6 μs. The difference of currents is the current leakage between the Rogowski coils. As the change of the rising rate of anode

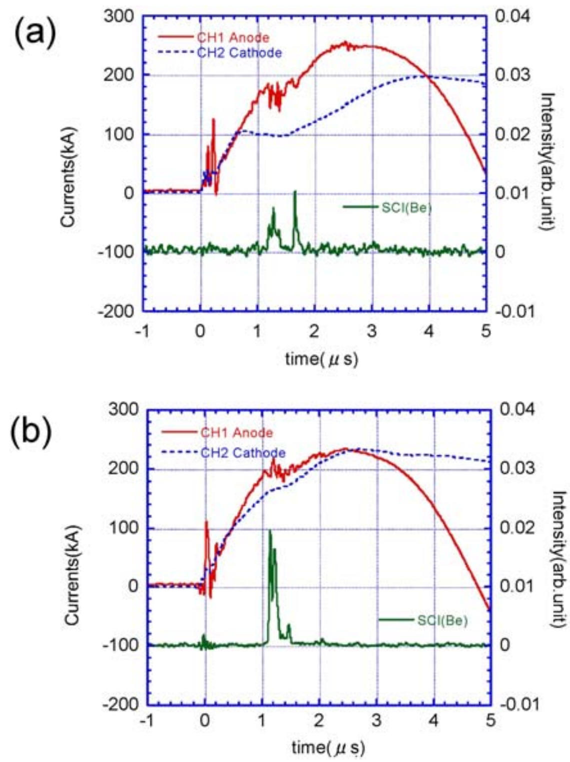

Fig.3 Discharge currents and x-ray signals at the neck spacings (a) 0.4 mm and (b) 0.6 mm. The diameter of the hole is 3 mm.

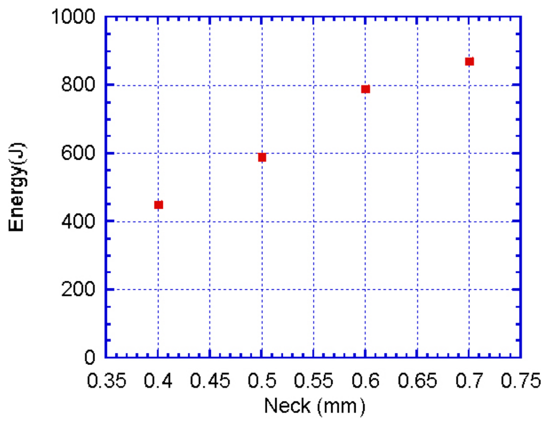

Fig.4 Dependence of input energy on the neck spacing. The diameter of the transmitting holes is 3 mm.

current is small around this moment, the leakage of the current is thought to occur near the cathode coil.

Input energy to the plasma can be evaluated by the analysis of current waveforms [2]. Figure 4 shows dependence of input energies to neck spacing. The diameter of the transmitting hole is 3 mm. The delay time of discharge from gas-puff is fixed to 0.37 ms. It is understood that input energy increases with increasing the neck spacing. The discharge current at the pinch time increases with the neck spacing and the input energy

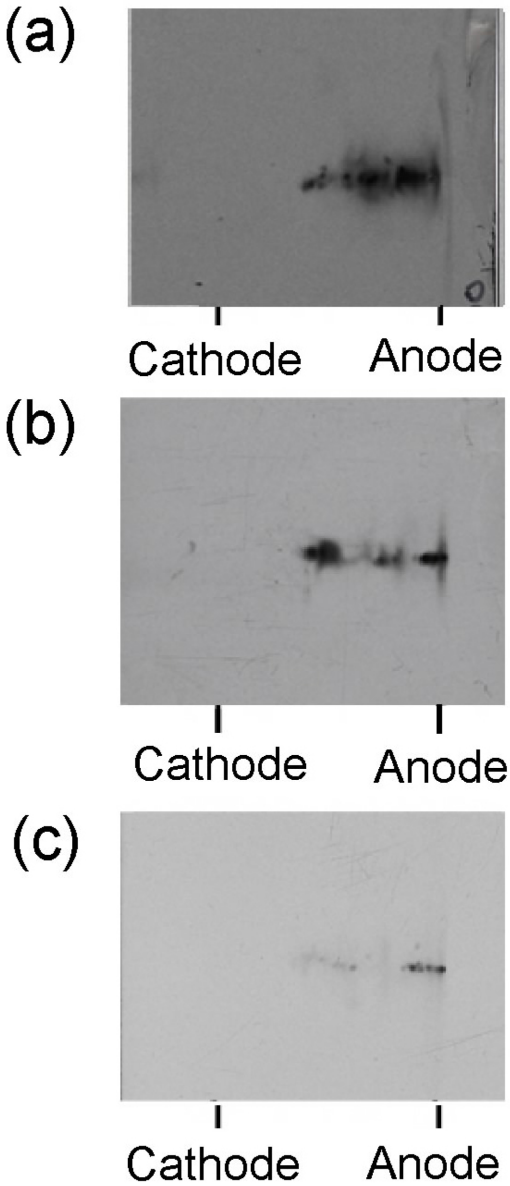

Fig.5 X-ray pinhole photographs at (a) hole diameter 2 mm and neck spacing 0.6 mm, (b) hole diameter 2 mm and neck spacing 0.7 mm, and (c) hole diameter 3 mm and neck spacing 0.7 mm.

increases.

4. X-Ray Pinhole Photograph

Figure 5 shows x-ray image of the plasma taken by an x-ray pinhole camera. The delay time is 0.37 ms.

In the case (a), the hole diameter is 2 mm, and the neck spacing is 0.6 mm. The photograph was exposed over 3 shots. The cloud structure appeared with hot spots. The interval of hot spots was about 6 mm according to the analysis of the image.

In the case (b), the hole diameter is same, and the neck spacing is 0.7 mm. The photograph was also exposed over 3 shots. Intensity of each hot spot is intensive. The interval of hot spots was about 7 mm.

In the case (c), the hole diameter is 3 mm, and the neck spacing is 0.7 mm. The photograph was exposed over 10 shots. The intensity of hot spots was faint, and the positions of them were not stable.

The results show that the intensity of hot spot is much different between the hole diameters 2 and 3mm. Spatial interval of the hot spots was wide, when the flow speed of the gas was slow. The interval became narrow when the space of the gas nozzle was narrowed and the gas flow speed was raised. At this condition, the input energy to plasma decreased, and x-ray radiation strength also decreased.

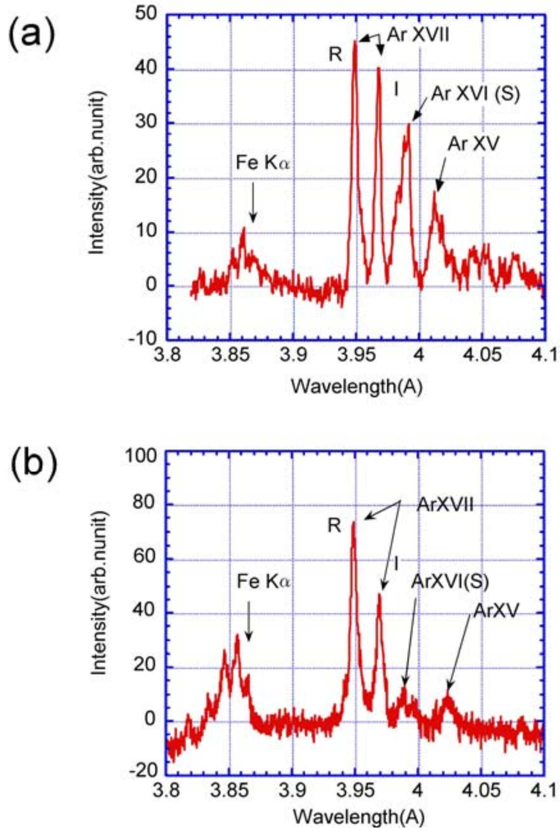

Fig.6 X-ray spectra of Ar ions at the hole diameters (a) 3 mm and (b) 2 mm. The neck spacing is 0.6 mm.

5. X-Ray Spectroscopy

X-ray spectroscopic measurement was conducted to evaluate the electron temperature of the hot spots. Figure 6 shows x-ray spectra obtained. The neck spacing is 0.6 mm and the delay time is 0.37 ms.

In the case (a), the hole diameter is 3 mm. The photograph was exposed over 20 shots, because x-ray emission was so weak. ArXVII He like resonance line (3.948 A), ArVII intercombination line (3.9691A), ArXVI Li-like satellite line (3.989 A) and ArXV Be-like satellite line (4.010 A) emission are intensive.

The spectra at short wave length are the second order spectra of Fe K_{α}(1.9360 A) and low ionized Fe ion lines. Fe is used in fixing bolts of electrodes. Those Fe lines would be excited by electron beam produced at the pinch of the plasma. The electron temperature was evaluated as 0.63 keV from the intensity ratio of He resonance line and Li-like satellite line.

In the case (b), the hole diameter is 2mm. It was exposed over 2 shot. Electron temperature was evaluated as 1.3 keV, although the emitted spectra were the same.

6. Summary and Discussion

The change of hot spot distribution and x-ray radiation were examined in a hollow gas-puff z-pinch device by changing the diameter of the transmitting holes and the neck spacing of the gas nozzle.

Between the cases of the hole diameter of 2 and 3 mm, x-ray emission was intense and electron temperature was high at 2mm. As the diameter of the hole changes flux of the gas, it was understood that high temperature plasma and intense x-ray emission were obtained by reducing the flux.

In the experiment of changing the neck spacing with fixing the hole diameter, it was confirmed that both input energy and x-ray emission increased with expanding the neck spacing. And, the interval of the hot spots was wide when the neck spacing was large.

When the neck spacing is wide, the gas speed is slow, and the gas distribution becomes wide. The discharge radius is wide, which contributes to the decrease of the load inductance and the increase of the current rise rate. The observed current at the pinch increases with the neck spacing. As a result, the input energy increases. It is thought that the growth of the RT instability is strongly affected by the gas distribution. The wavelength of the RT instability is large at the wide neck spacing.

The most suitable combination of the nozzle parameters in the series of experiments is that the neck spacing is 0.7 mm and the hole diameter is 2 mm.

References

[1] J. Shiloh, A. Fisher and N. Rostoker, Phys. Rev. Lett. **40**, 515 (1978).

[2] K. Takasugi, H. Suzuki, K. Moriyama and T. Miyamoto, Jpn. J. Appl. Phys. **35**, 4051 (1996).

[3] K. Takasugi, T. Miyamoto, K. Moriyama and H. Suzuki, AIP Conf. Proc. 299, 251 (1994).