Plasma Injection From Several Cesiated Hollow Cathodes into Large H- Ion Sources

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ABSTRACT. Compact cesiated hollow cathodes (CHC) has been developed and studied in two large multicusp H- ion sources at NIFS, aiming the long lifetime cathodes for plasma production in the neutral beam injectors. Results on hollow cathodes and power supplies improvement are described. Basic characteristics of multicusp source discharge, driven by several CHCs were studied. Key issues about simultaneous CHCs operation in high current discharge mode are discussed. Each of advanced CHC delivered stable and quiet income with current up to 70A for 5sec to source multicusp discharge. The hollow cathode operation with no Cs feed was obtained by using 30%Xe+70%H_2 gas mixture.

I. INTRODUCTION

Neutral beam injectors based on acceleration of negative ions has been reliably applied for plasma heating in NIFS and JAERI. At present all large multicusp plasma sources utilize multi-filament driven arc discharges for the production of dense plasma with H_2/D_2. Use of filament makes the discharge operation simple and reliable, and keeps an optimal temperature of the plasma grid for surface production with Cs seed. However, lifetime of the filament is restricted due to mainly evaporation/sputtering[1]. Also the tungsten evaporation from filaments accelerates the pollution of seeded Cs.

To develop the long lifetime plasma source, we started to establish the system of compact cesiated-hollow cathode which could be effective for the multicusp plasma sources of Neutral Beam Injectors (NBI) of Large Helical Device (LHD). Hollow cathode is considered to be a reliable cathode and can produce plasma injection for a long time. Cesium seed to CHC could provide H- ion production in ion source plasma grid as well. In contrast to previous experiments with a single high current hollow cathode, we have suggested to use the set of compact CHC for production of uniform plasma in the large area multicusp source. CHCs which were investigated and fabricated in BINP[2] were newly fitted to large multi-cusp H- ion sources on the LHD-NBI test stand[3]. Our purpose was to investigate the applicability of new CHC for LHD-NBI and to make the necessary R&D. The presented study was mainly concentrated on approval of the combined operation of several CHCs and establishing the necessary systems.

II. SINGLE CHC IN 1/6TH SCALE ION SOURCE

Ion source used consists of 1/6th scale multi-cusp plasma source (i.e., the dimension of 35 x 35 x ~18cm^3) with external magnetic filter and a small accelerator with single hole of 5mm in diam. Figure 1 shows a schematic drawing of 1/6th scale H- ion source.

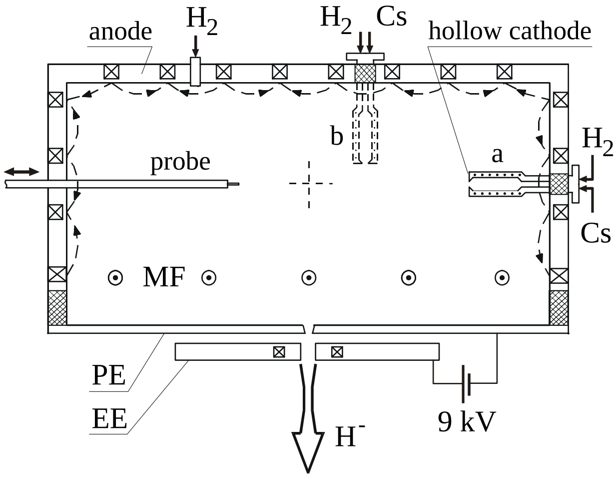

FIG.1. 1/6th scale H- ion source with Cesiated-Hollow Cathode on sidewall (a) and on back (b).

Structurally CHC was miniaturized to fit the filament feedthrough port of the source. CHC was made of Mo cylinder and was equipped with the ohmic heater. H_2 gas (or H_2 + Ar mixture) and Cs vapour were introduced into the cathode hollow (Fig.1). CHC body and Cs oven were preliminary heated. Cs coverage on hot Mo internal surface provided high electron emission current density. Additionally H_2 gas was introduced into multicusp plasma source.

The detailed results of this experiment were reported in the ref. 3. CHC provided a high multicusp discharge with current up to 60 A in the 10 sec mode and up to 30 A in cw mode. The discharge voltage was varied in the range 40 – 90 V by the Cs feed control. Discharge current attainable under the indicated voltage range was proportional to the H_2 flow rate into the CHC and to the area of CHC plasma emission aperture. Plasma density measured by Langmuir probe decreased with the distance from the CHC. The uniform plasma profile is expected for the distance of ~15cm between the CHCs (which is similar to the separation of the filaments in the multicusp source). Negative ion current of ~0.2mA was detected with 9 kV extraction voltage. This current value was similar to that obtained from the filament driven 1/6th source at 6 kW discharge power. Cs consumption was about 50mg/hr for the pulsed operation mode used.

III. STUDY OF CHC OPERATION WITH TWO CATHODES

Two CHCs were attached to the sidewalls of the 1/6th source (Photo of Fig.2). Two sets of CHC power supplies and two gas systems were used for gas feed to each CHC for study cathodes simultaneous operation with the independent bias.

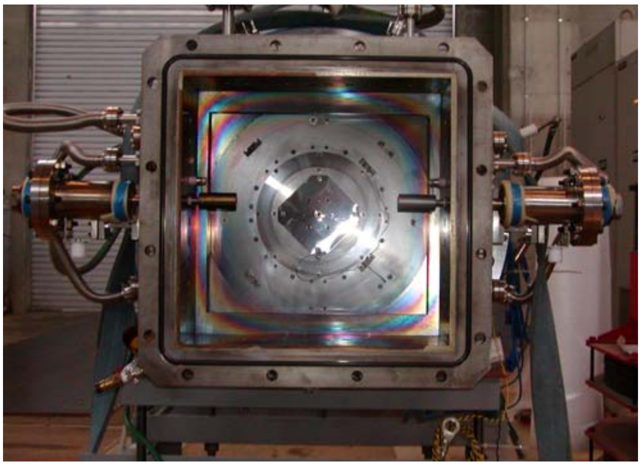

FIG.2. Photo of two CHCs attached to filament feedthrough ports of 1/6th scale source.

There were several improvements done after the first experiment with the single CHC. The special oven with the safe Cs pellets was built into each CHC to supply Cs independently (cylindrical volume attached to CHC in Fig.2). Ceramic insulator between CHC housing and filament feedthrough port was applied to operate at high oven temperature (~300 ^{o}C). Two Piezo gas valves were used for H_2 feed and for independent control of hydrogen pressures in two CHCs.

Arc power supplies for each CHC consisted of high voltage (up to 400 V) dc power supply (PS1) to start the discharge and of high power (up to 130V x 70A, 5sec) supply (PS2) for discharge support. PS1 and PS2 were connected in parallel to CHC circuit. Arc power were regulated by feedback to provide the constant current (c-c) mode. The others power supplies were used for the Piezo valve control, for the heating of CHC body and of the pellet oven. Power supplies were controlled remotely from the test stand console.

The continuous Cs discharge with the voltage of about 5-25V and current 0.5-1 A was ignited at first. The discharge was changed to high current H_2 + Cs mode when the PS2 power supply and hydrogen was pulsed to CHC.

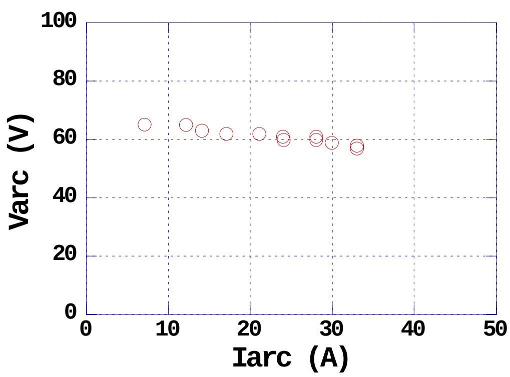

FIG.3. Discharge voltage vs discharge current with H_2 + Cs mode for 5s pulse.

In H_2 + Cs mode, discharge current was up to 35 A for 5 sec with the discharge voltage ranged from 50 V to 70 V (Fig.3). Thermal capacity of small cathode insert forming the CHC emission aperture limited the pulse duration. Maximum 50 A of discharge current was obtained for 1 sec with the small Mo insert. Essentially higher discharge power (50A for 5sec) was obtained with CHC equipped with the enlarged insert, as it tested at BINP test stand. Arcing and aperture melting was recorded at current-duration value >300As in the case of enlarged insert.

Simultaneous operation of two CHCs was first demonstrated in the 1/6th scale source at the decreased discharge current. Discharge current pulses for two CHCs simultaneous operation in the multicusp source are shown in Fig.4. CHC #1 delivers 17 A discharge current at the fixed level of c-c control, while CHC #2 keeps the smaller current of 8 A with the current oscillations. The low current operation of CHC #2 was caused by CHC emission aperture melting by the previous high current, several tens seconds pulse.

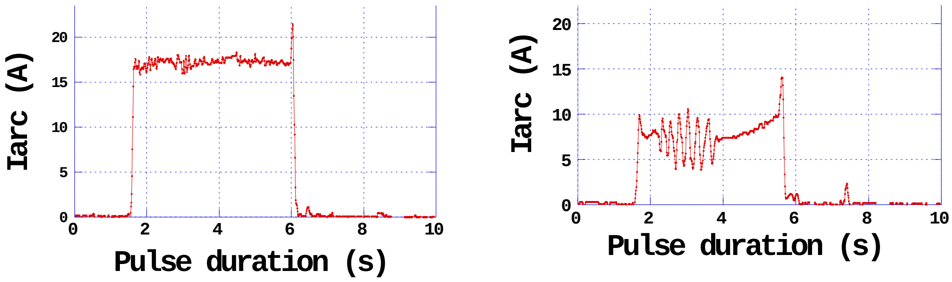

FIG.4. Pulses of discharge current for two CHCs simultaneous operation in the multicusp source.

IV. CHC OPERATION IN 1/3RD SCALE SOURCE

Work of three CHCs was tested in the experiment at the larger, 1/3rd scale H- ion source. The plasma chamber of this source has the dimensions of 38 x 62 x ~20 cm^3. Plasma grid, extraction and acceleration grids of the source have the multi-aperture structure with openings, drilled over the plasma chamber central area of about 25 x 25cm^2. Source and accelerator were pumped with the cryopump. Layout of 1/3rd scale source with the CHCs, attached to the sidewalls, is shown in Fig.5.

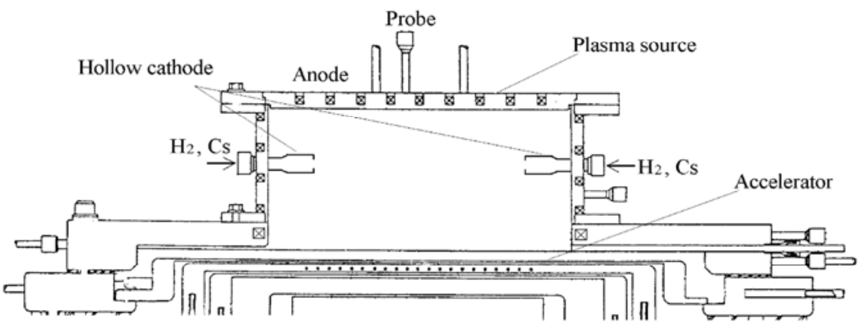

FIG.5. 1/3rd scale H- ion source with compact CHCs on sidewalls.

New CHC was designed by Yu. Belchenko for this experiment. For prevention of CHC aperture arcing and melting, the CHC body was isolated from the outer electrode having emission aperture (Fig.6). This outer electrode was connected to the plasma chamber anode with a series resistor for the discharge ignition. CHC was miniaturized to fit the small filament feedthrough port of the source, as it is shown in Fig.7. A mixture of H_2 and Ar gases was used for CHC feed. It permitted to operate at the lower Cs feed to CHC. Argon addition to hydrogen in the range 0.5-30% was tested in cathode cesium mode. Gas mixture was introduced into every CHC with the independent Piezo valve. High current arc power supply with the constant-voltage mode instead of previous c-c-mode was used for the discharge feedback control to reduce the open loop voltage, and its switch was doubled to prevent the pulse over length.

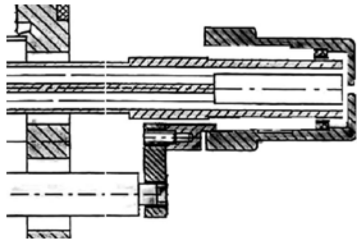

FIG. 6. Drawing of CHC with outer electrode.

Operation of single CHC and simultaneous work of two and of three CHCs with discharge current up to 70 A, 5 s per cathode was sequentially tested. Discharge current in range 50~70A and discharge voltage in range 20~70V were independently controlled for each cathode by power supply, gas and cesium seed. Discharge voltage and current has the quiet waveforms for ~5 s pulse, as it is shown in Fig.8 for the simultaneous work of CHC #1, 2, 4 with the 10% Ar and 90% H_2 gas mixture feed. Gas pressure in multicusp plasma chamber was measured with the baratron gauge. It was controlled in the range 0.5-4mT during the gas feed to three CHCs. No erosion and arcing of CHCs was recorded after 6 day/480 shots operation. One of CHC (# 3) was broken at the start-up due to mistake and the cesium pellets overheating.

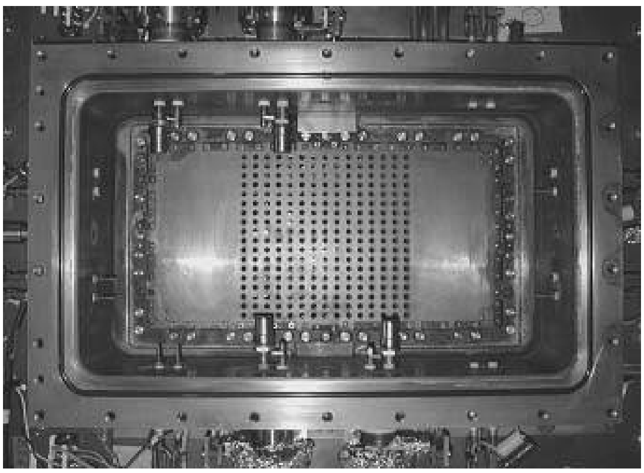

FIG.7. Photo of four CHCs in 1/3rd scale H- ion source.

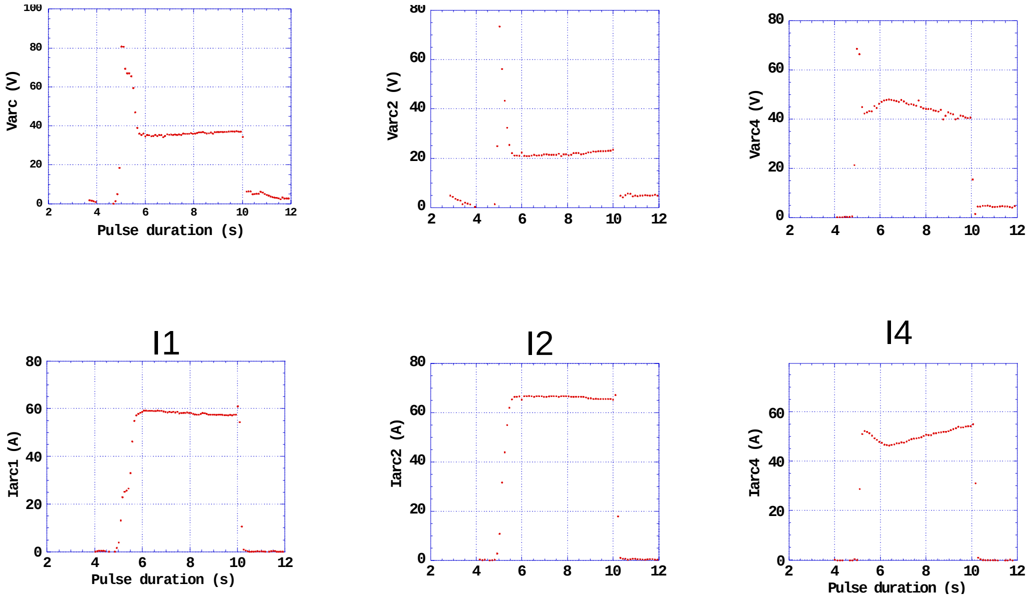

FIG.8. Waveforms of the discharge voltage (top) and discharge current (bottom) for CHC #1,2 and 4 simultaneous operation. A mixture of 10% Ar and 90% H_2 was fed.

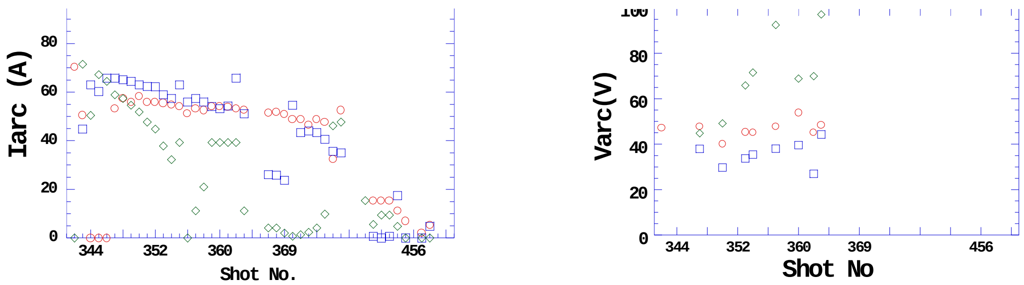

FIG.9. Passages of CHC #1, 2, 4 simultaneous operation. Circles- cathode #1, squares- cathode #2, diamonds- cathode #4.CHC currents (left) and voltages (right) were purposely spread for plasma study

Passages of CHC No.1, 2, 4 simultaneous operations are shown in Fig.9. CHC discharge currents were purposely spread for the plasma study. After shot No. 364, discharge current was diminished for trial of H-extraction/acceleration with the 3 CHC on. This first extraction trial was failed due to multi-aperture accelerator pollution by the cesium, which was injected during the preceding CHC study and during the mistake with the Cs oven overheat.

V. ARGON AND XENON GAS FEED

Single Hollow cathode operation without Cs seed and without cathode preliminary heating was tested in 1/3rd scale source too. 100% Ar, 100% Xe, or mixture of 30% Xe + 70% H_2 gases were introduced into hollow cathode in this case. The pressure of Xe in the plasma chamber was varied in the range 0.6 – 1.1 mTor, and of Ar – in the range 0.6 – 0.9 mTor. Stable discharge current up to ~70 A were obtained for 5 s pulse every 120 s (Fig.10). Discharge ignition was strongly dependent on kind of gases. Impedance of the Xe discharge has the lower value, than that for Ar discharge.

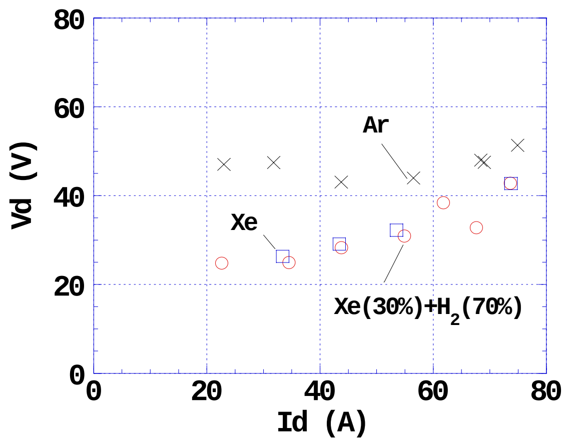

FIG.10. Discharge voltage vs discharge current for hollow cathode with rare gas or gas mixture feed. No Cs seed and no cathode preliminary heating was applied. Ar (crosses), Xe (squares) or 30% Xe + 70% H_2 gas mixture (circles) were introduced.

VI. SUMMARY

New system of plasma injection to the LHD-NBI 1/3rd scale multicusp plasma source with the several hot cesiated hollow cathodes was designed, produced and studied. CHC with the isolated outer electrode operates reliably and delivered quiet and stable discharge current up to 70 A per unit for 5-10 s pulse. System of three CHC and HC with no Cs were successfully tested. Arc power supply with c-v mode control made the operation of CHC and of electronics more reliable. It is important to note, that cesium is blocked inside the CHC hydrogen-argon discharge. The use of dc cesiated CHC can simplify the multi-aperture extraction. Plasma parameters and H- production from the multi-aperture source with HC will be studied in the near future to compare with those of filament driven H- ion source.

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