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Upgrade and experimental results of radio frequency ion source for neutral beam injector

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HIGHLIGHTS

- The RF ion source was developed in ASIPP for the first time.
- The gas control was employed for the initial plasma production successfully.
- The RF power was controlled for the stable plasma generation with high power.
- Long pulse operation was tested and analyzed with 400 s.

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ABSTRACT

A radio frequency (RF) ion source was designed and developed for neutral beam injector in Institute of Plasma Physics, Chinese Academy of Sciences (ASIPP). Recently, the RF ion source was upgraded with new RF power generator (50 kW with frequency of 1 MHz), a new matching unit and the faraday shield with water cooling. Two new methods were used for the ion source tests on the test bed. The high pressure was used for the ignition of plasma and change to low pressure of 0.3 Pa to maintain the plasma. The RF plasma can be generated without the start filament successfully. In order to avoid the plasma oscillation with high power, the RF power was set to increase with two stages without change the matching unit. High power of 46 kW with pulse length of 22 s was achieved on the test bed and the plasma duration can be extended too.

1. Introduction

The high power neutral beam injector (NBI) is a good way for the plasma heating and current driving for the fusion science researches [1–3]. The Experimental Advanced Superconducting Tokamak (EAST) was aim at the long pulse physical research. Two beam lines were designed and operated on EAST for plasma heating and relative researches [4]. The hot cathode bucket ion source was used on the EAST-NBI system [5], but the radio frequency (RF) source will be the most promising source can be operated with steady state [6–11]. Consider the long pulse requirement of EAST and the future fusion science researches, A RF ion source was designed and developed in Institute of Plasma Physics, Chinese Academy of Science (ASIPP) [12,13]. In the last year, the first plasma was achieved with low RF power. But only 10 kW RF power coupled into the RF source. After the upgrade of the RF power generator, RF matching unit and RF driver, high power of 46 kW was coupled into the plasma successfully.

2. Experimental setup

The schematic map of experimental setup with the matching network was shown in Fig. 1. The upgraded RF ion source test bed was shown in Fig. 2. It contains a 50 kW new RF power generator with RF frequency of 1 MHz, a dummy load (for the tests of RF power generator), a new matching unit and a modified RF driver. A mechanical pump with 14 L/s pumping speed and a molecular pump with 620 L/s were used for the gas pumping and can got background pressure of 10^{-3} Pa. The matching unit was developed without the HV transformer, the parallel capacitors C1 was 17.75 μF and the series capacitors C2 was 3.35 μF. The capacitors of C1 and C2 can be adjusted too. The RF coil was six turns with outer diame-

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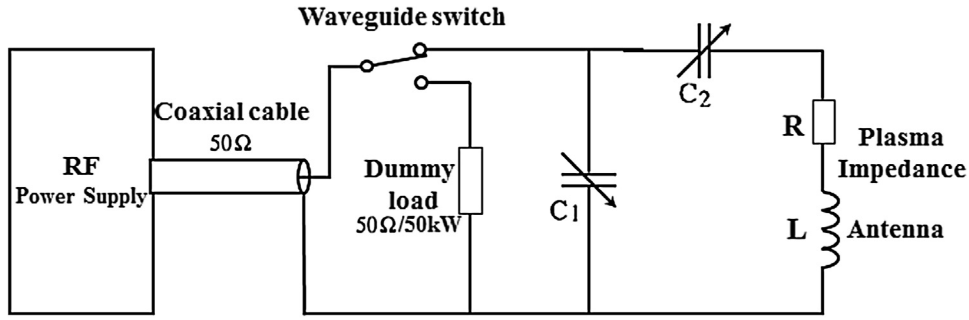

Fig 1. Schematic map of experimental setup with matching unit of RF ion source.

Fig. 2. Picture of RF ion source test bed.

ter of 6 mm and inner diameter of 4 mm. The distance between two turn was 3 mm. The inductance of coils was measured as 8.55 μH.

The faraday shield was modified with the active cooling, the detail structure was shown in Fig. 3. The diameter of Faraday shield was 200 mm, height was 120 mm and thickness was 4 mm. The cooling water went from the back plate and got into each cooling pipe in the side wall of Faraday shield. The cooling pipes were welded by several plates, the diameter of water cooling pipe was 3 mm.

3. Initial plasma generation for rf ion source

Initial RF plasma was much important for the stable of ion source because of the mismatching without plasma, the start filament was wildly used for initial plasma generation [14]. Besides, there had several other methods, such as use easy ignition gas (helium) [15], use two frequency RF power (one is for plasma generation and other for plasma maintenance), or use the high source pressure. But the lower discharge pressure of 0.3 Pa was encouraged due to the requirement of the accelerator [16]. In our case, the source pressure control method was used (the start filament was used before). The source pressure control method was to operate the ion source with high source pressure for plasma ignition and low pressure for maintenance. The gas inlet control method was shown in Fig. 4. Two gas valves were used with different pulse length to got high source pressure and held constant low pressure during source operation. The waveform of source pressure was shown in Fig. 5. The pressure was increased to about 4.5 Pa with two gas valves opened in 1 s, and the pressure decreased when close the gas valve 2 and reached 0.3 Pa in 2.5 s. According to the gas collision theory, the electrons impact the neutral gas probability is more than ten times with source pressure of 4.5 Pa to 0.4 Pa. The high pressure can help to generate initial plasma and the low pressure was better for the beam extraction. Compare with the start filament, it was much simple and cost less. Compare with the helium gas used, there had no impurities because only one gas to be used.

4. High performance plasma generate tests of rf ion source

In the last year, the RF plasma always oscillated when RF power higher than 10 kW. After the upgrade of the ion source system, this phenomenon also happened when RF power larger than 20 kW. When the initial plasma generated, the source pressure was changed and the parameters of the plasma was changed very fast too. The RF system matching was not good and higher reflected RF power. In order to get RF plasma with high RF power, the RF generator was control to output the power with two stages. In the first stage, the output RF power was set around 20 kW and kept it