AIP | Review of Scientific Instruments

Note: A new regulation method of stable operation of high power cathode ion source

C. C. Jiang, Y. H. Xie, C. D. Hu, Y. L. Xie, S. Liu, L. Z. Liang, and Z. M. Liu

Citation: Review of Scientific Instruments **86**, 056110 (2015); doi: 10.1063/1.4921705
View online: http://dx.doi.org/10.1063/1.4921705
View Table of Contents: http://scitation.aip.org/content/aip/journal/rsi/86/5?ver=pdfcov
Published by the AIP Publishing

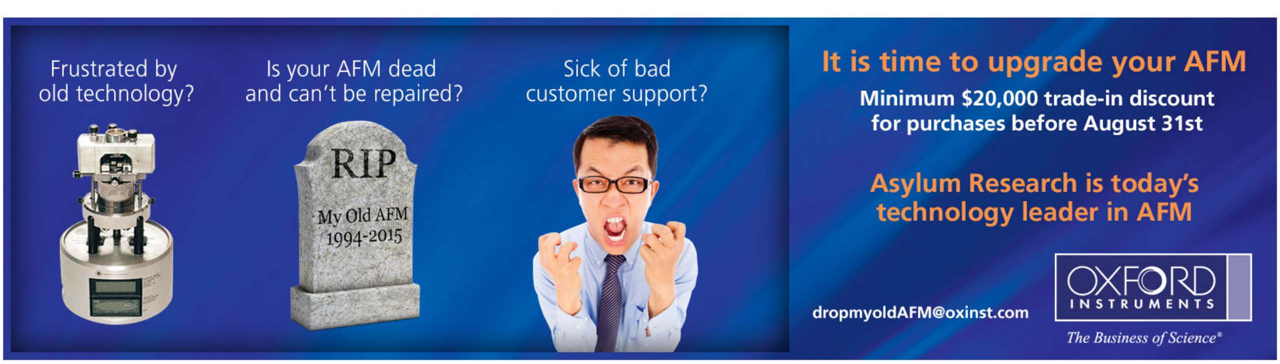
Articles you may be interested in
Erratum: "Arc discharge regulation of a megawatt hot cathode bucket ion source for the experimental advanced superconducting tokamak neutral beam injector" [Rev. Sci. Instrum.83, 013301 (2012)]
Rev. Sci. Instrum. **83**, 129903 (2012); 10.1063/1.4772571

High frequency operation of a hot filament cathode for a magnetized plasma ion sourcea)
Rev. Sci. Instrum. **83**, 02B910 (2012); 10.1063/1.3672470

Design and operating characteristics of new type cold cathode ion source
Rev. Sci. Instrum. **78**, 123301 (2007); 10.1063/1.2821236

Indirectly heated cathode arc discharge source for ion implantation of semiconductors
Rev. Sci. Instrum. **69**, 1688 (1998); 10.1063/1.1148866

Indirectly heated cathode arc discharge source for ion implantation of semiconductors
Rev. Sci. Instrum. **69**, 840 (1998); 10.1063/1.1148541



This article is copyrighted as indicated in the article. Reuse of AIP content is subject to the terms at: http://scitationnew.aip.org/termsconditions. Downloaded to IP: 210.73.24.91 On: Mon, 01 Jun 2015 00:25:17

REVIEW OF SCIENTIFIC INSTRUMENTS **86**, 056110 (2015)

Note: A new regulation method of stable operation of high power cathode ion source

C. C. Jiang, Y. H. Xie,[a] C. D. Hu, Y. L. Xie, S. Liu, L. Z. Liang, and Z. M. Liu
Institute of Plasma Physics, Chinese Academy of Sciences, Shushanhu Road 350, Hefei 230031, China

(Received 31 March 2015; accepted 13 May 2015; published online 28 May 2015)

The hot cathode ion source will tend to be unstable when operated with high power and long pulse. In order to achieve stable operation, a new regulation method based on the arc power (discharge power) feedback control was designed and tested on the hot cathode ion source test bed with arc discharge and beam extraction. The results show that the new regulation method can achieve stable arc discharge and beam extraction. It verifies the success of feedback control of arc source with arc power. © *2015 AIP Publishing LLC.* [http://dx.doi.org/10.1063/1.4921705]

The Experimental Advanced Superconducting Tokamak (EAST) is a fusion research device for the long pulse and high power plasma sciences.[1–3] In order to achieve high performance tokamak plasma, high power neutral beam injector (NBI) with long pulse is used to heat the plasma.[4–6] The ion source is the most important part of the EAST-NBI system, and the positive hot cathode ion source was used.

The intrinsic characteristic of cathode ion source is slow rise of the arc and beam current during the pulse length, which contributes to the cathode self-heating and the energetic electrons backstreaming from the accelerator into the ion source arc chamber. In order to achieve stable long pulse operation, the real-time feedback control method was used on the EAST-NBI ion source.[7,8] This method uses the classical Langmuir probe to measure the plasma density and feedback control the arc voltage to achieve stable discharge and beam extraction. The Langmuir probe needs to work in the plasma, so the heat loading on the probe tip will be considerable when the ion source is operated with high arc power and long pulse of 100 s.[9] The two pipes of cooling water were used to remove the heat loading, but it has a risk of water leakage. So a new method, which uses the arc power to real-time feedback control the operation of ion source, was analyzed and tested on the ion source test bed.

The ion source is a positive hot cathode ion source. There are 32 filaments with 1.5 mm diameter and 160 mm long installed in the long side of arc chamber, which are controlled to work in the emission limited mode. In order to achieve stable arc discharge and beam extraction and avoid the Langmuir probes in the arc chamber, the arc power is used to feedback control the operation of ion source. The principle of arc power regulation method can be seen in Fig. 1.

The principle of arc power regulation method is to use the arc power, which is the product of arc current and arc voltage, to compare with the given command value. Through the error amplifier and proportion integral derivative, outputs the control signal. The control signal is used to regulate the arc power supply on the ion source to achieve stable arc discharge and beam extraction.

The high current ion source has a large volume plasma chamber. High initial arc voltage (say 150 V) will help for the initial plasma generation. When the plasma generated, the arc current tends to increase because of the intrinsic characteristic. The arc power also increases and then it reaches the expected value; the arc power supply is regulated to decrease the arc voltage output to keep the expected arc power. So, we also call that the ion source works in the constant arc power (CP) mode.

The circuit of arc power regulation was designed and primarily tested in the latest campaign of ion source test experiment. The Langmuir probe was installed in front of the accelerator to measure the plasma density with negative bias voltage. The experimental results are compared with the probe feedback control mode with two arc power levels, which can be seen in Figs. 2 and 3. Fig. 2 shows the arc discharge with the arc power of 30 kW. The two shots have the same filament voltage of 7.2 V and gas input amount. It can be seen that the plasma needs 220 ms to get into the equilibrium state in the probe feedback control mode and 500 ms in the CP mode. When the plasma gets into the equilibrium state, the ion source can work much stable with two different feedback control modes and the arc voltage is decreased from 150 V to about 90 V. But the response time in the CP mode is much longer than the probe feedback control mode.

High power arc discharge with CP mode is also tested. The experimental waveform with probe feedback control mode and CP mode can be seen in Fig. 3. The filament voltage is 7.8 V and the arc power is about 70 kW. It can be seen that, in the probe feedback control mode, the plasma needs about 300 ms to get into the equilibrium state and it needs about 550 ms in the CP mode. Compared to the low power arc discharge, the ion source regulation time is

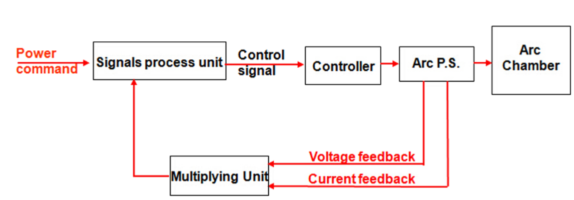


FIG. 1. The schematic map of arc power feedback control method.

a)Author to whom correspondence should be addressed. Electronic mail: xieyh@ipp.ac.cn.

 ©2015 AIP Publishing LLC
This article is copyrighted as indicated in the article. Reuse of AIP content is subject to the terms at: http://scitationnew.aip.org/termsconditions. Downloaded to IP: 210.73.24.91 On: Mon, 01 Jun 2015 00:25:17

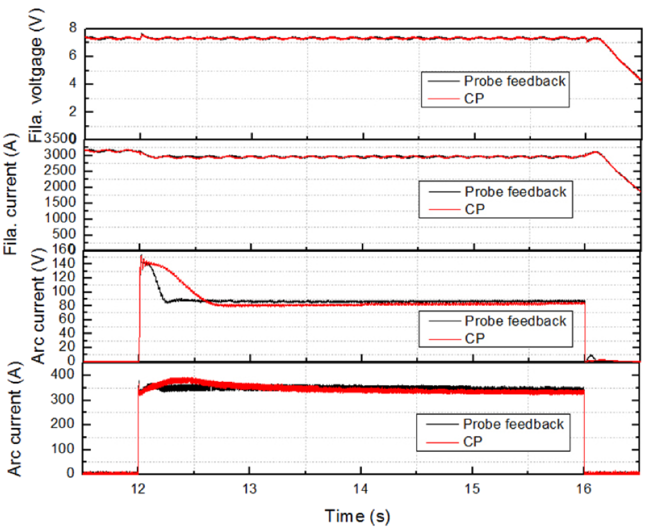


FIG. 2. The waveform of arc discharge with the probe feedback control mode and CP mode (30 kW).

increased little in the CP mode, but it increased about 50% in the probe feedback control mode. When the plasma gets into the equilibrium state, it is much stable with the pulse length both in the CP mode and probe feedback control mode. The results show that the ion source can get stable plasma with high power both in the probe feedback control mode and CP mode. It verified that the arc power regulation method can replace the probe feedback control method to achieve the stable plasma.

The ion accelerator is much sensitive to the ion beam optics. The accelerate voltage needs to match the plasma density in the arc chamber and keep good ion optics during the beam pulse. The beam extraction tests are also tested with two different ion source regulation methods, and a typical experimental result is shown in Fig. 4.

The ion beam was extracted in 2 s when the plasma discharged in 3 s. The arc voltage in the stable region is about 90 V, arc current is about 600 A, the extracted voltage is 50 kV, and the beam current is 30 A. When the beam is

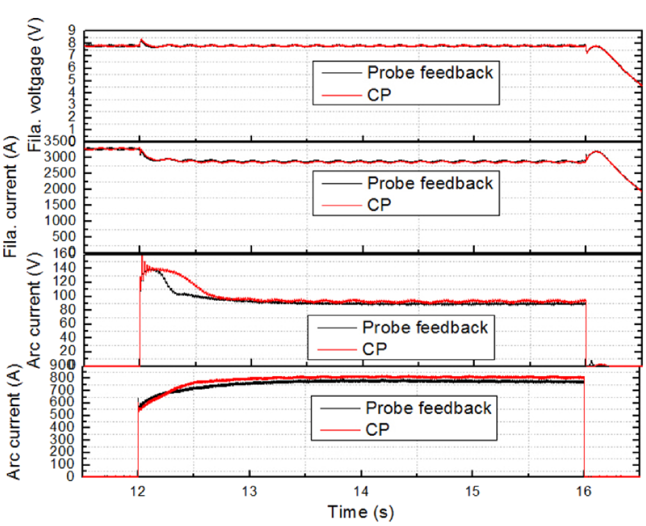


FIG. 3. The waveform of arc discharge with the probe feedback control mode and CP mode (70 kW).

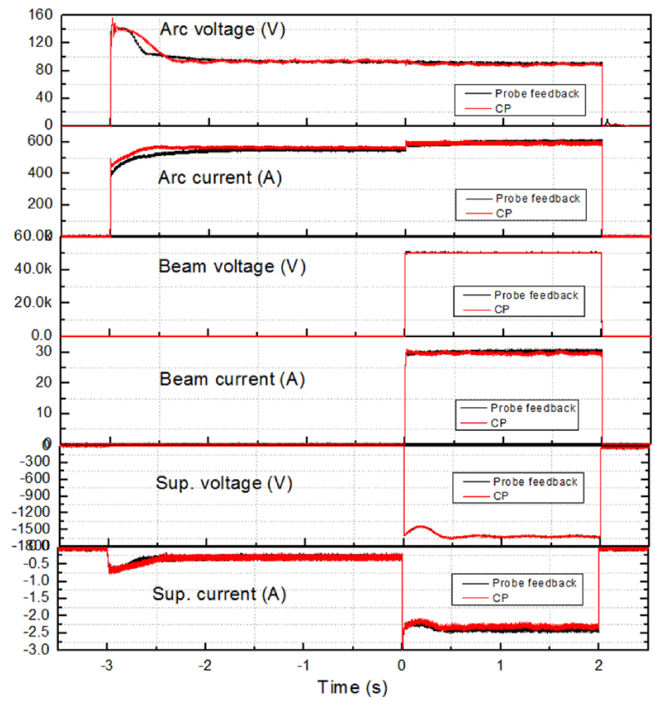


FIG. 4. The waveform of beam extraction with two different ion source regulation methods.

extracted, the arc voltage decreased to suppress the increase of arc current and beam current. So, the arc and beam currents keep no change during the beam pulse. The results show that the arc power regulation method can achieve stable beam extraction compared to the probe feedback control method.

At the initial beam extraction, the arc power was set to increase to 8% and keep this value during the beam extraction. So, the arc current has an increase at the initial of beam extraction.

The arc power regulation method is used on the high current hot cathode ion source for the first time. The results show that the arc power can be used to regulate the operation of ion source effectively. The output of arc voltage on the ion source is regulated swiftly when the plasma is generated. Compared to the density feedback control method, there needs no Langmuir probe in the arc chamber. It can avoid the risk of probe broken during the high power and long pulse operation.

In the circuit of arc power feedback control method, the digital signal was used as the feedback control signal. The resolution of digital signal is not high enough, so the control signal is a discontinuous signal and the feedback controlled plasma has a little fluctuation, which can be seen in Figs. 2–4. In the future, the resolution of digital signal needs to be increased, and the circuit also needs to be optimized to decrease the plasma regulation time. The time scale during the initial plasma generation and the plasma gets into the equilibrium state will be decreased to 300 ms. The characteristic of optimized arc power regulation method and more results will be analyzed and reported later.

This work is supported by the National Natural Science Foundation of China (NNSFC) (Contract No. 11405207) and the National Magnetic Confinement Fusion Science Program

This article is copyrighted as indicated in the article. Reuse of AIP content is subject to the terms at: http://scitationnew.aip.org/termsconditions. Downloaded to IP: 210.73.24.91 On: Mon, 01 Jun 2015 00:25:17

of China (Contract No. 2013GB101001), partly supported by International Science & Technology Cooperation Program of China (Contract No. 2014DFG61950).

[1]S. Wu and EAST Team, Fusion Eng. Des. **82**, 463 (2007).
[2]Y. X. Wan, J. G. Li, P. D. Weng, and EAST Team, Plasma Sci. Technol. **8**, 253 (2006).
[3]P. D. Weng and EAST Team, in ICEC 20: Proceedings of the Twentieth International Cryogenic Engineering Conference, 2005.
[4]B. Wu, J. F. Wang, J. B. Li, J. Wang, and C. D. Hu, Fusion Eng. Des. **86**, 947 (2011).
[5]C. D. Hu, L. Z. Liang, Y. L. Xie, J. L. Wei, Y. H. Xie, J. Li, Z. M. Liu, S. Liu, C. C. Jiang, P. Sheng, and Y. J. Xu, Plasma Sci. Technol. **13**, 541 (2011).
[6]J. F. Wang, B. Wu, and C. D. Hu, Plasma Sci. Technol. **12**, 289 (2010).
[7]Y. H. Xie, C. D. Hu, S. Liu, Z. M. Liu, J. Li, C. C. Jiang, and NBI Team, J. Fusion Energy **33**, 275 (2014).
[8]Y. H. Xie, C. D. Hu, S. Liu, C. C. Jiang, J. Li, L. Z. Liang, and NBI Team, Rev. Sci. Instrum. **83**, 129903 (2012).
[9]C. D. Hu and NBI Team, Plasma Sci. Technol. **15**, 201 (2013).

This article is copyrighted as indicated in the article. Reuse of AIP content is subject to the terms at: http://scitationnew.aip.org/termsconditions. Downloaded to IP: 210.73.24.91 On: Mon, 01 Jun 2015 00:25:17