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He–ICR cleanings on full metallic walls in EAST full superconducting tokamak

J.S. Hu *, J.G. Li, Y.P. Zhao, EAST Team

Institute of Plasma Physics, Chinese Academy of Sciences, Hefei, Anhui 230031, PR China

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ABSTRACT

He–ICR cleanings were successfully carried out in 2006–2007 on the full superconducting tokamak (EAST), which is an ITER-relevant experimental tokamak. Factors influence on He–ICR efficiency, such as magnetic field, ICRF power and working pressure were investigated. In EAST, the breakdown pressure for He–ICR cleanings could reach 10 Pa. The removal efficiency for H during 20 kW 4.5×10^{-3} Pa He–ICR cleaning was same as that in He–GDC cleaning (2 Pa, 4A). Highest H removal rate in EAST with full metallic material walls, 1.7×10^{22} H/h in 20 kW 3×10^{-2} Pa He–ICR, was higher by a factor of four than that in HT-7 with carbon limiter configuration.

1. Introduction

The Experimental Advanced Superconducting Tokamak (EAST) is a non-circular advanced steady-state experimental device. The first plasma discharge was achieved successfully in EAST in 2006. The scientific mission is to study the physical issues involved in steady-state advanced tokamak devices. The engineering mission is to establish the technology basis of fully superconducting tokamaks in support of future magnetic fusion reactors. Operation with a full metallic wall and molybdenum (Mo) limiters on EAST is also interesting as an ITER-relevant wall material [1,2].

A wide variety of wall conditioning techniques have been developed and applied in tokamaks for impurities and hydrogen removal [3]. Plasma-associated cleanings has been used and proven to be effective by running low energy conditioning plasmas such as glow discharge cleaning (GDC) [4], as well as various other methods based on RF techniques at electron cyclotron resonance (ECR) [5] and ion cyclotron resonance (ICR) [6]. However, extrapolation of wall and surface conditioning methods to a device such as ITER is not straightforward. Specific design related features, e.g. superconducting magnets, combined use of different wall materials and operational limitations, will preclude or limit the utilization of some of the most extensively used current surface conditioning techniques. The increased duty factor will result in a substantially different conditioning situation than in present tokamaks. Tritium removal techniques capable of operating in the presence of magnetic fields are desirable due to the permanent toroidal magnetic field in ITER. The permanent presence of toriodal field will preclude GDC cleaning; therefore, ICR conditionings are envisioned for in-between pulse cleaning. High hydrogen removal rates have been reported in ICR experiments in Tore Supra with He and D [6] and Textor with He [7].

In HT-7, ICR cleanings with various working gas, e.g. He, D_2, O_2 and mixture of He and O_2, were investigated from 1998 and He–ICR cleaning becomes routine methods for impurity removal in the interval of plasma operations [8–14]. In EAST, in the first experimental campaign with full metallic walls, ICR technique will be investigated for cleaning, boronization and oxidation. The main motivation is to study the utilization of RF for wall conditioning in the first ITER-like superconducting tokamak-EAST with a divetor configuration, which would provide technology basis of fully superconducting tokamaks in support of future reactors. In this paper, first results of He–ICR cleaning in EAST are introduced. Influences of RF power, working pressure, magnetic field, pumping speed on the He–ICR cleaning efficiency are investigated. He–ICR cleanings was also studied at the interval of plasma discharges. The comparison with He–ICR cleanings in HT-7 is presented in this paper.

2. Experiment setup

The EAST device (R = 1.75 m, a = 0.4 m) is first tokamak in the world with a full superconducting advanced configuration [1,2]. Its purpose is to establish a scientific and technological basis for the next generation of tokamak reactors. The superconducting coils can create and maintain a steady-state toroidal magnetic field of up to 3.5 T. For divertor operation, an elongation of 1.2–2 with single and double-null divertor will be used. In the initial phase of EAST in 2006&2007, the first walls were fully made of stainless steel with a Mo limiter. The total plasma facing areas was about 50–60 m^2. H_2 plasmas were achieved with circular and non-circular cross-section configuration and high fraction of H_2 up to 60–70% was found in the residual gases.

* Corresponding author. Tel.: +86 551 5591353; fax: +86 551 5591310.
E-mail address: hujs@ipp.ac.cn (J.S. Hu).

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ICR cleanings with wave frequency of 30 MHz have been performed in presence of permanent toroidal magnetic field (1–2 T) in EAST. A special ICRF antenna was designed for ICR wall conditioning, which located at low field side. The used RF power was in a range of 3–20 kW and the working pressure was in a wide range from 4×10^{-3} Pa to 10 Pa. The duty time of ICR wave was set at 0.3 s on/1.5 s off. During He–ICR cleanings, the wall temperature was about 80–130 °C. Four turbo-pump stations with nominal pump speed of 12 m^3/s were used for particles exhaust. Influences of RF power, working pressure and magnetic field on the He–ICR cleaning efficiency were investigated. He–ICR cleanings was studied at early phase of the campaign and the interval of plasma discharges. He–ICR cleanings before/after oxidation experiment was studied, too.

3. Results and discussion

In EAST, due to good resistance match between ICR antenna and ICR plasmas, helium could be easily breakdown. In EAST, He–ICR plasmas at high pressure up to ∼10 Pa were easily obtained which much different from that in HT-7, where He–ICR plasma could only be obtained at pressure lower than ∼0.2 Pa.

Normally, He–ICR plasmas in EAST spread fully in the inner vessel, as shown in Fig. 1. The CCD cameras monitoring RF discharges in toroidal and poloidal directions indicated that ICRF plasmas were toroidally uniform (like on circular machines) but poloidally located mostly at the machine low field side, LFS (ICRF antennas side). With the toroidal magnetic field varied from 1 to 2 Tesla, no difference could be observed from discharge light and partial pressure of particles, which means the magnetic filed possibly has little to no influence on He–ICR cleaning.

After long baking and more than 60 h He–GDC, plasmas in EAST could not be easily obtained due to impurities after shut down. Boronization or He–ICR at early phase of EAST operation would be useful for improving the plasma properties. During He–ICR at early phase of EAST operation, the partial pressure of hydrogen and impurities, such as water and carbon-oxides, would increase, as shown in Fig. 2, which was beneficial for their removal and provided a clean wall for plasma discharge. After 350 min He–ICR cleaning, normal H_2 plasma discharges were obtained.

After five days of H_2 plasma operation (about 800 shots), abundant H_2 retention on the walls lead high recycling during plasma discharge, which made plasma density controls difficulty. Due to He–ICR would be operated in the presence of magnetic field, He–ICR cleaning could be easily operated at the interval of plasma discharges without requirement to shut down the current in superconducting coils, which is quite important for EAST and further reactors, such as ITER. Fig. 3 shows the typical time evolutions of particles partial pressure during He–ICR cleaning at the interval of H_2 plasma discharges. It is easily found that after H_2 plasma discharge, H_2 partial pressure decreased fast due to exhaust by pumping and absorption on the walls. If He–ICR cleaning is done after the discharge, H_2 would sustain at a high partial pressure, which was beneficial for its exhaust by pumping. After the He–ICR cleaning, the H_2 plasma density could be easily controlled, and plasma properties, such as pulse length, were improved. Possibly due to 'clean' walls in EAST, the partial pressure of impurities decreased during the He–ICR cleaning. It has been indicated that the most impurities in the vessel were ionized, which was as similar as that in HT-7 [10].

Fig. 1. He–ICR plasma in presence of 1 Tesla of toroidal magnetic field in EAST (CCD picture).

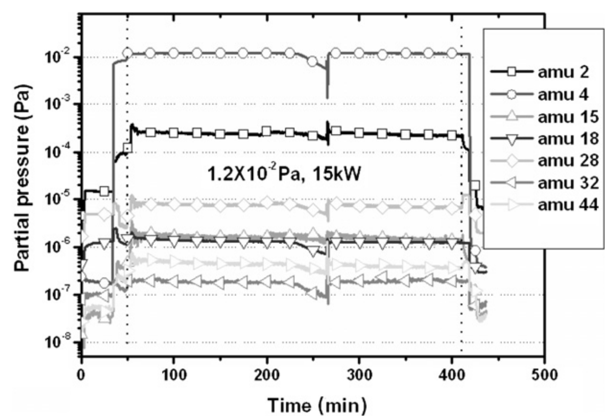

Fig. 2. Typical time evolutions of partial pressure of particles during He–ICR cleaning at early phase of EAST operation.

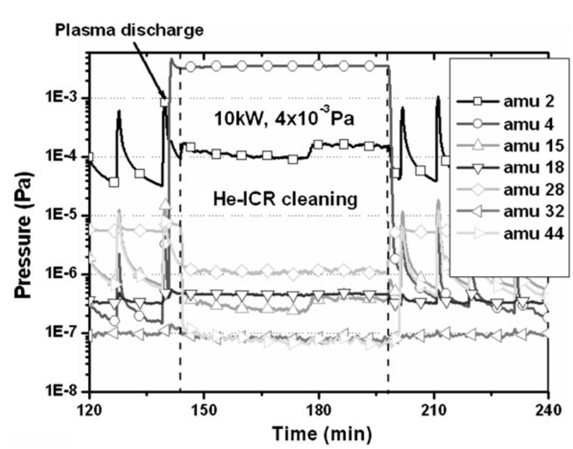

Fig. 3. Typical time evolutions of particles partial pressure during He–ICR cleaning at the interval of H_2 plasma discharges.

At the end of the campaign of EAST, O–ICR wall conditioning was completed. During He–ICR cleanings before the O–ICR experiment, the behaviors of particle partial pressure were as similar as that in Fig. 3. However, after He/O–ICR experiments, He–ICR has high removal efficiency for impurities but low removal efficiency for hydrogen, as shown in Fig. 4. The reason was that during O–ICR wall conditioning, most hydrogen was removed and lots of impurities, such oxygen and oxides, would be absorbed on the walls. This He–ICR cleanings also indicates that wall conditioning would influence the impurities and hydrogen removal efficiency.

At the low working pressure, such as lower than 0.3 Pa, high RF power and high working pressure would promote H and C removal, as shown in Fig. 5. However, pumping speed decrease while the working pressure is over 0.3 Pa, as shown in Fig. 6. Then, to increase of RF power and working pressure seems no effect on improving H and C removal rates. The highest H removal rate was 1.8×10^{22} H-atoms/h in 0.3 Pa 20 kW He–ICR cleaning, which was higher than that HT-7 by a factor of 4 in 0.1 Pa 40 kW cleaning. This indicated that pumping speed is also very important for He–ICR cleaning. It is important to increase pumping speed for high pressure He–ICR cleaning.

There are lots of differences between EAST and HT-7 for He–ICR cleaning. In EAST, ICR antenna was specially designed for RF wall conditionings whereas it shared with ICRF heating system. The shape and location of two antennas were different. This is a possible main reason that He–ICR would be done in EAST at a high pressure of up to ~10 Pa, whereas it could be only operated lower than 0.2 Pa in HT-7. Many other factors would influence the results from HT-7 and EAST, such as volume, plasma facing surface and materials, pumping speed, structure of vessels and plasma fuels. The volume of EAST vessel is ~40 m^3 whereas that of HT-7 is ~5 m^3, which would influence the energy density during He–ICR cleaning; The plasma facing surface in EAST is about 50–60 m^2 whereas that in HT-7 is ~12 m^2, which would influence the effective cleaning areas. The plasma facing material in present study in EAST was fully metallic whereas that in HT-7 has 20% doped graphite with SiC coating, which would influence the cleaning ability on the surfaces. EAST is a divetor machine whereas HT-7 is a limiter device, which would influence the cleanings zone. Plasma fuels in EAST before the present research was H_2, whereas it is D_2 in HT-7. Those are possible reasons that the highest H removal rate in EAST was 1.8×10^{22}H-atoms/h in 0.3 Pa 20 kW He–ICR cleaning, which was higher than that HT-7 by a factor of 4 in 0.1 Pa 40 kW cleaning. However, detail comparison between the both devices is quite difficulty. It required more data to distinguish which factor is most important and how they influence on the removal efficiency of He–ICR cleaning.

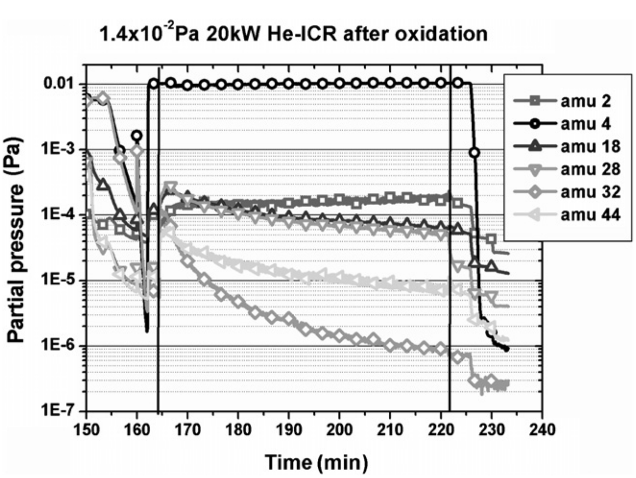

Fig. 4. Time evolutions of particles partial pressure during He–ICR cleaning after oxidation experiment.

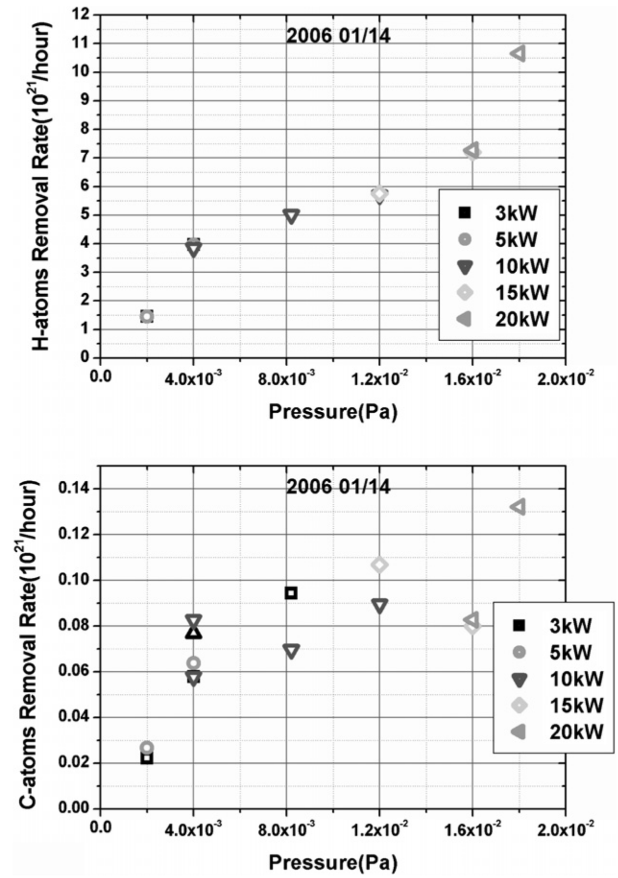

Fig. 5. Average removal rates for H and C in low pressure He–ICR cleanings in EAST.

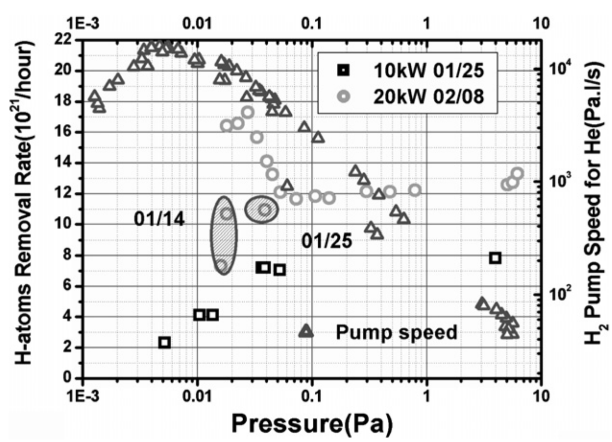

Fig. 6. Average removal rates for H and C in high pressure He–ICR cleanings in EAST.

4. Summary

He–ICR cleanings were successfully carried out on ITER-relevant full metallic material wall in EAST in 2006 and 2007, which are beneficial for establishing a scientific and technological basis of wall conditioning for the next generation of tokamak reactors, such as ITER.

In EAST, He–ICR cleaning was testified as an effective method for hydrogen removal and also beneficial for impurities removal in early plasma operation and after oxidation experiments. In EAST, breakdown pressure for He–RF cleanings could reach 10 Pa. The removal efficiency for H during 20 kW 4.5 E–3 Pa He–ICR cleaning was as the same as that in He–GDC cleaning (2 Pa, 4A). Highest H removal rate, 1.7×10^{22} H/h in 20 kW 3×10^{-2} Pa He–ICR, was higher than that in HT-7 by a factor of four. Detail comparison removal efficiency between HT-7 and EAST is quite difficulty. It required more data to distinguish which factor is most important and how they influence on the removal efficiency of He–ICR cleaning.

Factors influence on He–ICR efficiency, such as magnetic field, ICRF power and working pressure were also investigated. High RF power and working pressure would promote particles removal, however, results from both partial removal rate and CCD pictures showed that the influence of toroidal magnetic field (1–2 T) was small. The RF power will be increased and pumping speed at high pressure will be improved for hydrogen and impurities removal. High power He–ICR on new graphite wall will be studied in next campaign in EAST.

Acknowledgments

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