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RESULTS OF EXPERIMENTAL STUDIES AT CYLINDRICAL INERTIAL ELECTROSTATIC CONFINEMENT FUSION DEVICE

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SİLİNDİRİK EYLEMSİZ ELEKTROSTATİK SIKIŞTIRMALI FÜZYON CİHAZINDA ALINAN DENEYSEL SONUÇLAR

Abstract:

In this study, a cylindrical inertial electrostatic confinement (IEC) device, designed and constructed at the Saraykoy Nuclear Research and Training Center (SNRTC), is introduced and the initial results are presented. This device is designed for neutronic fusion studies based on Deuterium–Deuterium (D-D) reactions. The cylindrical IEC device consists of cylindrical anode and a grid-type cylindrical cathode. The anode, also called vacuum chamber, is held at ground potential and has 11 ports to connect the vacuum pump, vacuum gauge, current control load, ion sources and other peripherals. The cathode is placed at the center of chamber and high negative voltage is applied to it. Maximum cathode voltage is 95 kV. The operating pressure range is between 1×10^{-4} mbar and 9×10^{-4} mbar. Two Inductively Coupled Plasma (ICP) type ion sources are used to increase the ion concentration and hence the collision cross section at the axis of the cathode. The neutrons generated by fusion reactions were detected by a helium-3 filled neutron detector. The maximum total neutron production rate was measured at about 5×10^{7} neutrons per second with the present configuration.

Özet:

Bu çalışmada, Sarayköy Nükleer Araştırma ve Eğitim Merkezi (SANAEM)’ nde tasarlanıp kurulan silindirik eylemsiz elektrostatik sıkıştırmalı bir füzyon cihazı ile alınan ilk sonuçlar sunulmuştur. Bu cihaz, Döteryum-Döteryum (D-D) füzyon reaksiyonlarına dayanan nötron çalışmaları için tasarlanmış olup silindirik anot ve ızgara tipi silindirik katottan oluşmaktadır. Vakum odacığı olarak da adlandırılan anot, sıfır potansiyelde tutulur ve vakum pompası, vakum ölçer, yüksek voltaj besleme elemanı, iyon kaynakları ve sistem için gerekli olabilecek diğer bağlantılar için 11 adet girişe sahiptir. Katot ise vakum odacığının merkezine yerleştirilir ve katoda yüksek negatif voltaj uygulanır. Uygulanan maksimum katot voltajı 95 kV’dir. Çalışma basıncı 1×10^{-4} mbar ve 9×10^{-4} mbar aralığındadır. Vakum odacığındaki iyon konsantrasyonunu arttırmak için iki adet indüktif eşleşmiş plazma (ICP) tipi iyon kaynağı kullanılır ve böylece katot ekseni boyunca füzyon olasılığı da artar. Füzyon reaksiyonları ile üretilen nötronlar, helyum-3 dolu bir nötron detektörü ile tespit edilir. Mevcut sistem ile yapılan çalışma sonucunda elde edilen maksimum toplam nötron sayısı yaklaşık olarak 5×10^{7} nötron/saniyedir.

Keywords: D-D reactions, fusion, neutron, inertial electrostatic confinement, high voltage, ion source

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Anahtar Kelimeler: D-D reaksiyonları, füzyon, nötron, eylemsiz elektrostatik sıkıştırma, yüksek voltaj, iyon kaynağı

1. Introduction

The IEC device is one of the small fusion devices that relies on electrostatic potential differences between two concentric electrodes to confine and accelerate ions to fuse with one another in the central region (Rider, 1995; Donovan, 2011; Weidner, 2003).

Generally, IEC devices are classified as spherical and cylindrical type. Farnsworth and Hirsch studied and built the first IEC device in the late 1960s (Hirsch, 1967) and Farnsworth first patented IEC (Farnsworth, 1966). In recent years, IEC studies have taken place in United States, Japan, South Korea, Australia, Iran and Turkey. Generally spherical geometry has been used for IEC devices in these studies (Miley and Murali, 2014; Bölükdemir, 2013). Cylindrical geometry is a prime alternative that has been widely studied for IECs. Cylindrical geometry for an IEC device was originally developed in the United States (Chacon, Bromley and Miley, 1997) and later spread to other countries (Oura, et al., 2006). The objective of considering this geometry is to obtain a dense core region extending along the axis of the cylinder. Because of very long source, this geometry is especially useful for neutron sources.

In Turkey, the first IEC studies started with low pressure spherical inertial electrostatic confinement device, at the SNRTC for D-D fusion reactions (Bölükdemir, 2013). The SNRTC-IEC device consists of a spherical chamber, 300 mm in diameter, and a grid-type spherical cathode in which a high negative voltage was applied. The anode (vacuum chamber) of the device was held at ground potential while the cathode voltage was 85 kV. The maximum total neutron production rate was measured at about 3.6×10^5 n/s with this device.

In the present study, the features of a newly designed and constructed IEC device with cylindrical geometry and the results of preliminary fusion studies carried out in this device are presented.

2. Material and Method

The cylindrical IEC device used in this study consists of a cylindrical vacuum chamber made of aluminum as the anode and a central cylindrical grid made of iron as the cathode with insulator surrounding the dip. The anode is 650 mm in inner diameter and 700 mm length, the cathode is 100 mm in inner diameter and 200 mm length, consisting of 8 rods, each 5 mm in diameter. The cathode has 90% transparency with this geometry. The cathode with insulator and anode are shown in Figure 1.

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Figure 1a. The cathode with insulator and anode

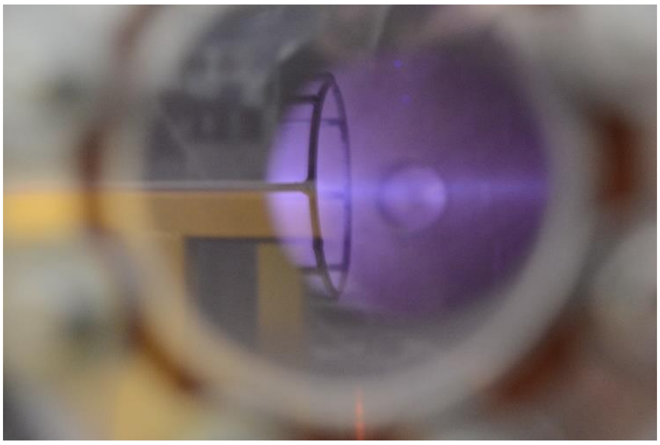

Figure 1b. A gas discharge test case at high pressure

This cylindrical IEC device has 11 ports reserved for the vacuum pump, gauge, high voltage feedthrough, ion sources and other peripherals. Two ICP deuterium ion sources are used to obtain a high concentration of ions inside the cathode. The addition of an ion source to the IEC fusion device enhances fusion reactions by allowing a lower operating gas pressure and by providing a beam-like ion energy distribution (Takamatsu, Masuda, Kyunai, Toku and Yoshikawa, 2006; Masuda et al., 2001). The high voltage power supply has 100 kV output. Mechanical and turbo pump are used to provide vacuum conditions in the operating range of 1×10^{-4} mbar and 9×10^{-4} mbar. A picture is given capture for gas discharge test case at high pressure (1×10^{-1} mbar) in Figure 1b.

This cylindrical IEC device is constructed in order to explore D–D reactions. The D–D reaction has two equally probable reaction paths to release either high-energy neutrons or protons (Krane, 1988; Bölükdemir, Akgün and Alaçakır, 2013).

$$D + D \rightarrow {}^{3}He\ (0.82\ MeV) + n\ (2.45\ MeV) \qquad (50\%)$$

$$\rightarrow T\ (0.82\ MeV) + p\ (2.45\ MeV) \qquad (50\%)$$

Generated neutrons are detected by a helium-3 filled neutron detector, Thermo FHT 752SH. The detector, calibrated with Am-241 Be-9 3.7 GBq neutron source, has a polyethylene moderator. The shielding parameters are calculated by using MCNP5 (Monte Carlo N-Particle Transport Code) computer code for protection against the ionizing radiation.

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As a result of calculations, it is estimated that 45 cm water pool shielding in 2 cm thickness of plexiglas wall or 35 cm paraffin block is sufficient for protection from 2.45 MeV neutrons. This water pool is located between the IEC chamber and all experimental equipment in order to protect equipment and staff. Furthermore, two paraffin blocks (each of 35 cm thickness) are placed at left and right side of the cylindrical IEC chamber. Additionally, a thin layer (2 mm) of lead is placed on the front of the chamber to stop the Bremsstrahlung (x-rays) radiation due to the electrons produced in the chamber. A picture of the cylindrical IEC device with all components is given in Figure 2.

Figure 1. A view of the cylindrical IEC device with all components

3. Results

A mechanical and a turbo pump are used for creating the required vacuum conditions. The base pressure is measured using an ion gauge. The system was operated with two deuterium ion sources at 95 kV voltage between the anode and the cathode at 6×10^{-4} mbar pressure. Both ion sources are water cooled and have radiofrequency antenna with three turns measuring 40 mm in diameter. The antennas are fed by two separate radiofrequency power supplies, one 175 Watt and the other 85 Watt momentarily. Also, 4 kV of DC kick voltage is applied to the ion sources separately. When the system is operated at these conditions, D-D fusion reactions are achieved and preliminary neutrons measurements are obtained with Thermo FHT 752SH neutron detector.

In order to obtain the neutron production rate, Equation 1 is used. Here, the neutron production rate, namely fusion rate F, is related to the count rate observed by the detector D_n, plus geometry and efficiency factors for the detector and is given as follows (Piefer, Santarius, Ashley and Kulcinski, 2005; Bölükdemir, et al., 2013):

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$$F = \frac{D_n\, 4\pi\, R_{det}^2}{A_{det}} \qquad (1)$$

where R_{det} is the distance between the detector and the device center, A_{det} is the detector surface area. In this study, R_{det} is 380 mm and A_{det} is 2920 mm^2. The preliminary detector measurement D_n is 81000 n/s. For this value of detector measurement, the neutron production rate is obtained as 5×10^7 n/s.

4. Conclusions

The results given in this study are the preliminary measurements obtained with the aforementioned system configuration and operating conditions. The maximum total neutron production rate is measured at around 5×10^7 n/s and it is found to be comparable with that of literature, i.e. 1×10^7 n/s (Miley and Murali, 2014) under similar conditions. In the future studies, it is planned that the deuterium ions generated in the two ion sources will be focused by coils placed at the exit of the ion sources and directed to the vacuum chamber as a beam. Therefore, the ion concentration at the cathode in the vacuum chamber will be further increased. Consequently, the fusion probability of deuterium ions and hence the neutron production rate will also be increased.

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6. Bibliography

1) Bölükdemir, A.S., Akgün, Y. & Alaçakır, A. (2013). Preliminary results from experimental studies of low pressure inertial electrostatic confinement device. Journal of Fusion Energy, 32, 561–565. Doi: 10.1007/s10894-013-9607-z.

2) Bölükdemir, A.S. (2013). The construction and experimental studies of inertial electrostatic confinement fusion device in low pressure (PhD. Thesis, Gazi University, Ankara). Erişim adresi: http://www.acikarsiv.gazi.edu.tr/index.php?menu=2&secim=10&YayinBIK=9480#.

3) Chacon, L., Bromley, B. & Miley, G. (1997, October). Prospects of the Cylindrical IEC Fusion Device as a Neutron Source. Proceedings of the 17th IEEE/NPSS Symposium Fusion Engineering, San Diego, CA.

4) Donovan, D. C. (2011). Spatial profiling using a time of flight diagnostic and applications of deuterium-deuterium fusion in inertial electrostatic confinement fusion devices (PhD Thesis, University of Wisconsin Fusion Technology Institute, Madison). Erişim adresi: http://fti.neep.wisc.edu/pdf/fdm1392.pdf.

5) Farnsworth, P.T. patented June 28 (1966). Electric discharge device for producing interaction between nuclei. U.S. Patent #3,258,402. Erişim Adresi: https://patentimages.storage.googleapis.com/40/00/36/4437c3b8018b75/US3258402.pdf.

6) Hirsch, R. L. (1967). Inertial-Electrostatic Confinement of Ionized Fusion Gases. Journal of Applied Physics, 38, 4522. Doi:10.1063/1.1709162.

7) Krane K.S. (1988). Introductory nuclear physics (2nd. ed.). New York: John Wiley.

8) Masuda, K., Taruya, K., Koyama, T., Hashimoto, H., Yoshikawa, K., Toku H., Yamamoto, Y., Ohnishi, M., Horiike, H. & Inoue, N. (2001). Performance characteristics of an inertial electrostatic confinement fusion device with a triple-grid system. Fusion Technology, 39(3), 1202–1210. Doi:10.13182/FST01-A174.

Makale Gönderim Tarihi:27/04/2018
Makale Kabul Tarihi:05/06/2018

9) Miley, G.H. & Murali, S.K. (2014). Inertial electrostatic confinement (IEC) fusion. Doi: 10.1007/978-1-4614-9338-9.

10) Oura, S., Yamauchi, K., Watanabe, M., Okino, A., Kohno, T. & Hotta, E. (2006). Neutron and Proton Measurements of Cylindrical Radially Convergent Beam Fusion. Journal of the Korean Physical Society, 49, 384-388. Erişim adresi: http://www.jkps.or.kr/journal/list.html?page=7&sort=&scale=10&key=&keyword=&s_v=49&s_n=9(6)&pn=vol&TG=vol&year=2006.

11) Piefer, G. R., Santarius, J. F., Ashley, R. P. & Kulcinski, G. L. (2005). Design of an ion source for 3He Fusion in a low pressure IEC device. Fusion Science and Technology, 47(4): 1255-1259. Doi: 10.13182/FST05-A860.

12) Rider, T. (1995). A general critique of inertial-electrostatic confinement fusion systems. Physics of Plasmas, 2(6), 1853-1872. Doi:10.1063/1.871273.

13) Takamatsu, T., Masuda, K., Kyunai, T., Toku H. & Yoshikawa, K. (2006). Inertial electrostatic confinement fusion device with an ion source using a magnetron discharge. Nuclear Fusion, 46, 142–148. Doi:10.1088/0029-5515/46/1/016.

14) Weidner, J. W. (2003). The production of 13N from inertial electrostatic confinement fusion (Master of Science, University of Wisconsin Fusion Technology Institute, Madison). Erişim adresi: http://fti.neep.wisc.edu/pdf/fdm1210.pdf .

Makale Gönderim Tarihi:27/04/2018
Makale Kabul Tarihi:05/06/2018