Experiments on a new actively cooled cathode for the inertial electrostatic confinement fusion device to extend the operational time

Alireza Asle Zaeem*, Morteza Sedaghat movahhed, Ali Bagheri, Mojtaba Kabir, Emad Rezaei

Plasma and nuclear fusion research school, Nuclear science and technology research Institute, Tehran, Iran
* *Email: aaslezaeem@aeoi.org.ir*

Abstract
Inertial electrostatic confinement devices are one of the early designed fusion neutron generators that are usually used for the laboratory plasma ion confinement studies. If deuterium gas is used, relatively high energy ions could generate fast neutrons during the well-known D-D nuclear fusion reaction process. Since the cathode electrode is exposed to high energy ions, this electrode suffers from high temperatures up to the melting point. Therefore, steady state operation is not possible for an extended time particularly at high power operations. This paper reports on the design and construction of a new cathode, including its high voltage feedthrough for the IR-IECF device at the plasma and fusion research school. Deionized water is used for cooling of the electrode to prevent high voltage breakdown. Both the theory and experimental results represent excellent heat removal even at more than three kilo-watts of ion power in continuous mode of operation.
.

Keywords: nuclear fusion, inertial electrostatic confinement (IEC), actively cooled cathode, heat removal

Introduction

Inertial electrostatic confinement (IEC) is a typically ion converging instrument that uses strong electrostatic fields between two co-center spherical electrodes to confine the ions in a hot dense region. This device is being used for several applications such as neutron source, glow discharge plasma and ion-material interaction studies. High energy field-emission electrons emits from the cathode then the ions are generally produced due to electron collisions with the background gas while the electrons cross the cathode to the anode. Due to the strong convergent electric field between the electrodes, ions start moving back and forth through the transparent cathode. These phenomena end in the formation of a glow plasma region inside the cathode. If deuterium gas is used, the high energy ion collisions cause the nuclear fusion reaction with a certain probability which is proportional exponentially with the ions energy [1]. The fast 2.45 MeV neutrons releases during the fusion reactions and these neutrons are detectable using ^{3}He proportional counter [2]. Experiments indicate that the neutron production rate is exponentialy related to the cathode voltage and linearly is proportional with discharge current [2,3]. The former fact is related to the exponential characteristics of D-D fusion cross section reactions with the incident ion energy or the cathode voltage and the later is a sign of beam-target fusion reactions in IEC devices[1]. Since the internal electrode (cathode) is not completely transparent then some fractions of the incoming ions, would collide with the cathode and rapidly warm it to high temperatures or melting point. To avoid melting the cathode there have been some proposals such as using magnetically confined electrons instead of cathode [4] or cooling the cathode with deionized water [5]. Here in this article design, fabrication and initial tests of a new actively cooled cathode for IR-IECF [6] device is reported.

Experimental Preparation of the materials

Cathode over heating is a major problem for almost all of the IEC devices at high power operations; therefore, here we have designed a new actively cooled cathode including high voltage feedthrough as is depicted on Fig (1). The cathode is made of three millimeter pipe 304 stainless steel which finally forms a ten centimeter sphere. To overcome the high voltage surface script, the feedthrough consists of two concenter quartz cylinders as well as a *sounding alumina pipe. A thirty-centimeter Alumina cylinder with stabiles steel head is considered to joint two concentric quartz tubes. The cathode pipes are crossed through the middle of the internal quartz tube. During the construction of the feedthrough, epoxy resin has been used to fill the internal quartz tube and the space between the two quartz tubes in order to maintain the vacuum pressure. The cathode electrode usually is connected to negatively high voltage bias, therefore to avoid electric shock, deionized water must be used for the cooling purposes.*

Fig (2) indicates the simulation result of cathode temperature as a function of ion heating power for different cooling water flows (water follow is related to the pumping power) Simulations have been performed using COMSOL multiple physics software. After fabrications of the new cathode including the feedthrough, in order to choose suitable pumping power we considered the result of simulations on Fig (4) which indicates the cooling water temperature. Therefore a householder water purification pump was used. This pump is able to flow the water in the feedthrough with the rate of 0.2 liter per minute. A second pump was used to recirculate the deionized water in a closed loop.

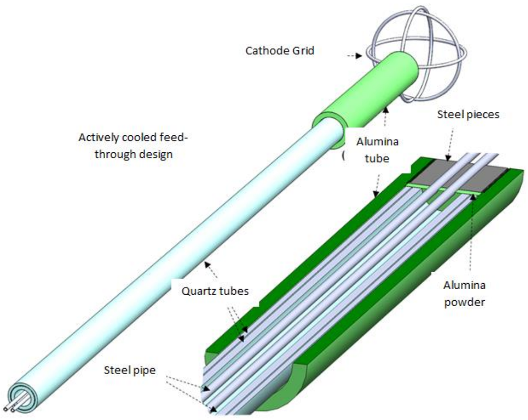

Fig (1) Cathode electrode including the high voltage feedthrough design

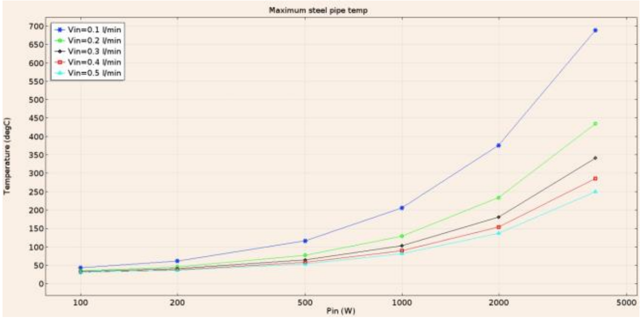

Fig (2) COMSOL simulation results of cooled cathode temperature as a function of input power for different coolant water flow

Fig (3). Fabricated actively cooled cathode for IR-IECF

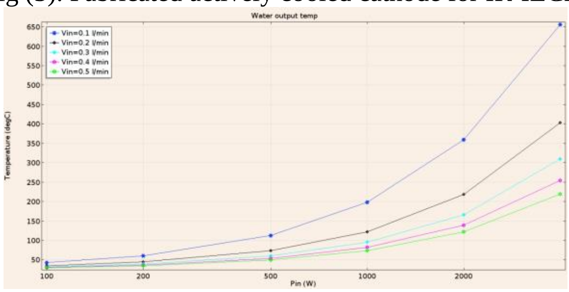

Fig (4). COMSOL simulation results of cooling water temperature as a function of input power for different coolant water flow

Newly constructed feedthrough was installed in the IR-IECF vacuum chamber and the turbot molecular pump was used to evacuate the chamber up to 10^{-5} mbar. Then the gas injected to the chamber up to 10^{-3} mbar pressure. High voltage power supply connected to the cathode and the continuous operation of the device with glow discharge plasma is depicted on Fig (5).

Results and discus

Before the construction of new cathode simulation results using COMSOL multiple physics software represents that for the 0.2

liter/min water flow as the coolant, it is possible to load up to 750 Watts of ion heating power Fig (4). Beyond this limit the coolant will change to steam phase. But it should be noted that the cathode is transparent and less than ten percent of incoming ions would coliid with the cathode. Therefore, it will be possible to operate the IR-IECF device even more than 5000 watts of power without any overheating problem.

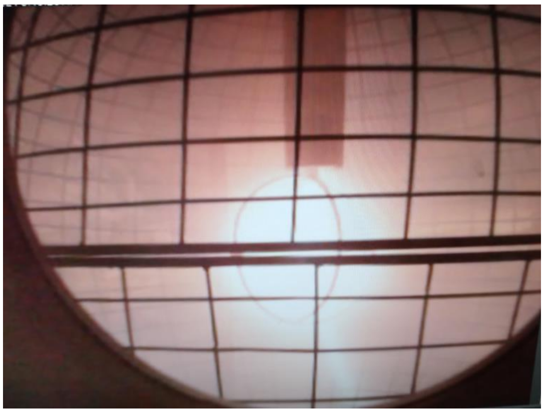

Fig (5) New cathode during continuous operation at 20kV and 100 mA.

Fig (3) represents the fabricated new fee thorough. Temperature increment of cooling water was measured as a function of input power. Measurements were performed while the circulated water was in thermodynamic equilibrium with the cathode Fig (6). The experiments represent that newly constructed cathode is able to operate at high powers without overheating while the circulating deionized water remains in the liquid phase. Therefore, the new cathode removes the produced heat suitably.

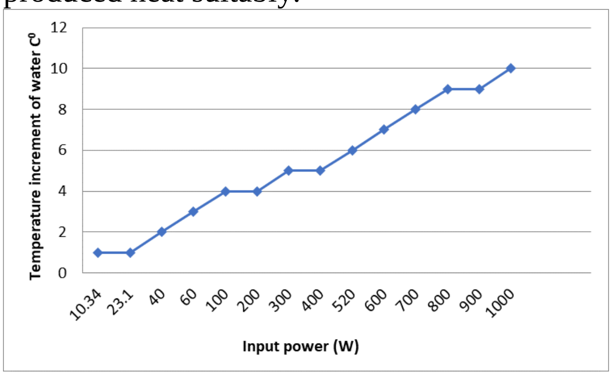

Fig (6). Measured recirculating water temperature as a function of operational power for Argon gas

Conclusions

A new actively cooled cathode has been designed and fabricated for IR-IECF device. This new electrode not only prevents the high voltage surface script but also has deionized water recirculation channels to prevent over-heating of the cathode electrode. The primary experiments using Argon and deuterium feeling gas represents fairly satisfactory cooling during high power operation.

Acknowledgments

The authors would like to appreciate plasma and fusion research school of nuclear science and technology research institute for the financial support of the project.

References

[1] Alireza Aslezaeem et al Preliminary results of a miniature cylindrical inertial electrostatic confinement fusion device equipped with inductively coupled plasma generator, Journal of Instrumentation 14 (07), T07007 (2019).

[2] Alireza sale Zaeem, Hassan GhafooriFard and Asghar sedighzadeh "Discharge current enhancement in inertial electrostatic confinement fusion by impulse high magnetic field" Vacuum 166, 286-291(2019).

[3] K. Masuda et al "Cathode grid current dependence of D(d, n) 3 He reaction rates in an inertial electrostatic confinement device driven by a ring-shaped magnetron ion source" Plasma Phys. Control. Fusion, vol. 52, no. 9, p. 95010, (2010).

[4] J. Park, N. A. Krall, P. E. Sieck, D. T. Offermann, M. Skillicorn, A. Sanchez et al "High-energy electron confinement in a magnetic cusp configuration" Phys. Rev. X 5 021024, (2015).

[5] Seltzman, Andrew "Design of an actively cooled grid system to improve efficiency in inertial electrostatic confinement fusion reactors" GEORGIA INSTITUTE OF TECHNOLOGY DEPARTMENT OF PHYSICS (2008).

[6] V. Damideh et al "Experimental Study of the Iranian Inertial Electrostatic Confinement Fusion Device as a Continuous Neutron Generator" journal of fusion energy (2011).