The Design of a Neutron Generator Using the Inertial Electrostatic Confinement ofDeuterium Plasma

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An Undergraduate Level Submission

Summary
Aneutron generator was designed that uses the inertial electrostatic confinement (IEC) of a deuterium-based plasma to generate neutrons by the process of fusion.A two-stage high-vacuum system was designed that uses a rotary-vane pump and turbo-molecular pump.A pressure measurement system was designed that uses a Pirani pressure-gauge and an ionization pressure-gauge. A high-voltage system was designed that uses an off-the-shelf high voltage power supply and a Cockcroft-Walton voltage-multiplier circuit. A neutron detection system was designed that usesa Helium-3 neutron detector. Safety considerations in the operation of the device are discussed.It is expected this device is to be constructed in 2013-2014.

1. Introduction

The Inertial Electrostatic Confinementdevice is asystem that uses electrostatic fields to accelerate and confine ions.The electrostatic field in a spherical IEC deviceis created by high voltage spherical wire-frame electrodes (an inner negative cathode and apositive outer anode).One use of such a device is the production of neutrons via the DDnfusion reaction (see equation 1).

$$^{2}_{1}D + ^{2}_{1}D \rightarrow ^{3}_{2}He(0.82MeV) + ^{0}_{1}n(2.45MeV) \tag{1}$$

The theoretical principal behind IEC is as follows: the reaction chamber is initially filled with a high purity gas, such as deuterium, to undergo fusion.This gas should be kept at a low pressure so that its behaviour is primarily dictated by molecule-wall collisions (IE its pressure should be in the molecular flow regime or about 10^{-2}Torr[1] in the designed system.An extremely high, negative voltage (in the order of tens of kilo-Volts) is applied to the inner cathode while a high positive voltage (in the order of hundreds of Volts) is applied to the outer anode. There is a small fraction of background ionization of the reactant gas inside the chamber due to cosmic ray interactions[2].The deuterium ions from this initial ionization are attracted towards the inner cathode while the electrons are attracted towards the outer anode. The movement of these initial

[1] 1 Torr is defined to be 1/760th of atmospheric pressure, ~133.332 Pa or ~1mmHg
[2] In larger system running at lower pressures, the fraction of initial ionization is so small that other means such as ion guns or electron emitters must be used. See [9].

ions ionize the gas atoms along their path (much of the ionization will be due to electron bombardment of the deuterium gas) until the entirety of the gas is turned into plasma.Neglecting interactions with other ions, as an approximation, the energy acquired by the deuterons as they transverse the space between the anode and cathode is equal to the difference in electrical potential between the anode and cathode. The deuteronsthat miss the cathode collect in the focus of the cathode and create a region of higher density ions and electrons. When a deuteron is incident on this region of higher densityions and electrons, there is a probability that it will interact with deuterium ions trapped in the focus of the potential wellwith enough energy to tunnel through the Coulomb barrier and undergo nuclear fusion.

The essential components of an IEC device are: high-vacuum, high-voltage, and neutron detection. The high–vacuum system is used to evacuate the reaction vessel of any air and then back-fill it with reactant gas. The high-voltage system is used to apply high-voltage to the electrodes. The neutron detection system is used to detect any neutrons produced.

2. Overview of Design

The IEC device designed uses a two-stage high-vacuum system that is measured in a two-stage vacuum measurement system. In the design, deuterium is supplied via an external storage tank through a regulated valve. The DDn reaction itself is to occur within a six way Conflat cross [1] with glass viewports.The high negative voltage for the inner cathode is to be provided by a multi-stage Cockroft-Walton voltage-multiplier circuit [2]. High positive voltage is to be provided with an off-the-shelf high voltage power supply. Neutron detectionin the design is to be accomplished with a Helium-3 neutron detector.

3. High Vacuum System

In the design, the whole high-vacuum system (Figure 1) is isolated into three sections: the vacuum back-end; the gas and measurement section; and, the reaction chamber. Each of these sections is isolated by a valve.

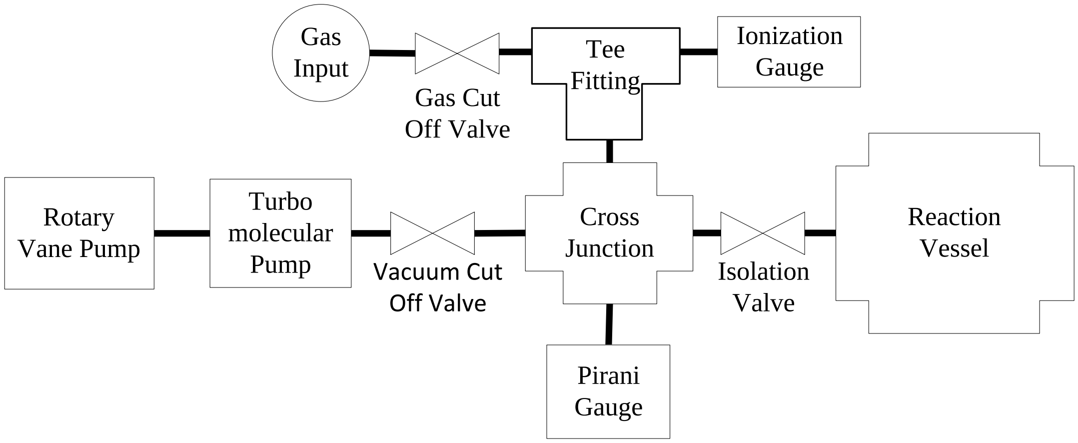

Figure 1: Diagram of the High Vacuum System

In the vacuum back-end, the system is to usetwo stages of pumping to reach pressures in the high vacuum regime. The first stage is a VIOT VDP5 [3]dual-stage rotary-vane pump[4]thatlowers system pressure to 10^{-2}Torr. The second stage is a LeyboldTurbovac 151 [5]turbomolecular pump[4] that is capable of an ultimate pressure of 10^{-9}Torr. It is unlikely that an ultimate system pressure of 10^{-9}Torr will be reached due to system leakage.

The rotary-vane pump is to connect to the turbomolecular pump via a wire-reinforced polyvinyl chloride (PVC)vacuum hose. The turbomolecular pump is to be water cooled by a water pump connected to a water reservoir.

In the measurement section, pressures ranging from atmospheric pressure to 10^{-4} Torr are to be measured with a Gransville-Phillips 275 Mini-Convectron[6] Pirani pressure-gauge [4]. To cover the full range of measurable pressures, the Pirani pressure-gauge divides its output signal into three distinct voltage regimes.Pressure readings from the Piranipressure-gauge are to be readby an Arduino Microcontroller [7] through a voltage divider.Pressures ranging from 10^{-4}Torr to 10^{-9}Torr are to be measured using a Gransville-Phillips 271 ionization pressure-gauge [4] and controller.The ionization pressure-gauge is to be fitted into a DN40 Conflat tee fitting. This tee fitting is to be attached to a four-way DN40 Conflat cross thatwill also holdthe Pirani pressure-gauge. Copper gaskets are to be used on all Conflat fittings.

The reaction chamberwill be a six-way DN160Conflat cross. TheConflat cross is to be fitted with a viewport. The high voltage feed-troughs areto be installed on the top and bottom of the Conflatcrosssuch that the cathode will be supported from the bottom and the larger anode will hang from top. The DN160 Cross is to be fitted to a DN160-DN40-DN63 Conflat Tee with a blank flange installed on the DN63 end. The measurement section is to be attached to the reaction chamber on the DN40 section of the Conflat Tee via a DN40 Conflat connection. Blanks are to be installed on the rest of the ports of the cross.A gas feed system is to be installed into the vacuum boundary by a ¼” NPT brass globe valve attached to an adapter on the DN-40 Tee fitting.To prevent leakage, the threads of the NPT fitting are to be sealed with the Hysol 1C: a vacuum greasethat is rated down to 10^{-9}Torr.

4. High Voltage System

The high-voltage system is to consist of a high-voltage negative out, positive ground power supply; a high voltage positive out, negative ground power supply; and two sphericalstainless steel electrodes (see Figure 2).

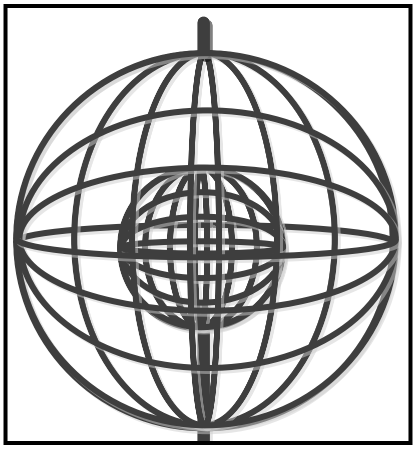

Figure 2: Drawing of the spherical electrodes used in IEC

The high-voltage negative out, positive ground power supply is to berated to 25kV and is to be built from a 2kV gas sign transformer attached to a five stage Cockcroft-Walton voltage multiplier circuit using 5kV ceramic capacitors. This configuration enables very high voltage, low current power to be supplied to the inner cathode. The high-voltage positive out, negative ground power supply is from an Ortec 556 [8] power supply set to a voltage of 400 Volts.

The electrodes are to be built from 1/8" stainless-steelwirethatwill be Metal-Inert-Gas (MIG) welded into a shape such as the one show in figure two.Stainless-steelrod will connect the electrodes to the high voltage feed through and act as mechanical support for the electrodes.

5. Neutron Detection System

Neutron detection will be done through a Helium-3 detector positioned outside of the reaction chamber. The detector will be encased in paraffin blocks that will thermalize any neutrons entering the detector and thereby increase their probability of detection. A neutron detection rate that is above the background detection rate is evidence that the DDn reaction is occurring.

6. Safety Considerations

Given that IEC devices operate at high voltages, certain precautions must be taken to ensure safe operation. Issues that require attention are: high-voltage, radiation, and deuterium combustion.

High voltagesafety will be ensured by using high-voltage test equipment on all diagnostic equipment.Grounding straps and rubber mats are to be used when any work needs to be done on high voltage equipment. Capacitors will be discharged via a short circuit between the terminals with a high resistance bleed resistor. A protective shield will surround the Cockcroft-Walton voltage multiplier circuit when in operation.

Radiation from the IEC device will be in two forms: X-rays and neutrons. The X-ray production comes from bremsstrahlung reactions produced inside of the plasma, and also from energetic electrons bombarding the structural materials. Neutrons are produced through DDnreactions. To address radiation safety, experiments will be performed inside of anisolated, shielded facility with no humans present. The high-voltage power will be turned on remotely so that the system can operate with no humans present.A video camera will be set up in the view port so that the reaction can be viewed.

It is understood that deuterium gas is flammable, and precautions will be taken to prevent combustion by ensuring that there is no oxygen within the reaction chamber. However, it is also recognized that the system operates at low pressure (10^{-2}Torr of deuterium), and the combustion energy potential is relatively low. From a combustion perspective, the IEC device, is likely safer than operating an acetylene torch.Potential safety concerns from combustion of deuterium gas will be addressed by ensuring the operating room is evacuated when the device is at power.

7. Conclusion

The preliminary design for a device which uses the inertial electrostatic confinement of deuterium ions to generate neutrons has been completed. It is expected that this device will be constructed at the University off Ontario Institute of Technology (UOIT) in 2013-2014. Equipment procurement is ongoing. Initial testing will be performed by using inert helium followed later by the use of hydrogen gas.It is expected that when operating at full capacity, the device will produce somewhere in the range of 100,000 neutrons per second. It is anticipated that an operating license from the Canadian Nuclear Safety Commission(CNSC) will be required to licencing will be required to use deuterium gas in the UOIT-IEC Mark I device.

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[14] The Fusor Online Community at http://www.fusor.net

9. Acknowledgements

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