Constructing a Farnsworth-Hirsch fusor for neutron generation

Tomas Lindén, Szabolcs Galambosi, Feliks Kivelä, Vladyslav Litichevskyi, Sami Maisala, Pekko Metsä, Jouko Orava, Heimo Saarikko, Otto Solin, Raimo Turpeinen

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A Farnsworth-Hirsch fusor is a device using only an electric field to ionize, accelerate and confine ions to produce fusion reactions. A fusor provides likely the simplest way to achieve deuterium-deuterium fusion. Fusors have been used as neutron sources for activation analysis, isotope generation and material research.
Because of its relative simplicity, small size and low cost a fusor can be used as an educational tool teaching students to work with radiation detection, radiation safety, plasma physics, high voltage systems, vacuum technology, electronics and data analysis.

A cylindrical fusor was built for testing and development purposes in a joint project between the Department of Physics at the University of Helsinki and the Helsinki Institute of Physics. Stable plasma discharges were achieved with that device. Currently a spherical fusor is being built primarily for educational purposes. The status of the project is described and preliminary results from the fusor project are presented.

Contents

Introduction

The pioneers of inertial electrostatic confinement fusion (IEC):

P. Farnsworth (1906-1971). Television pioneer, invented the Farnsworth fusor ca 1964 [1].

O. Lavrentiev (1926-2011). Presented the idea of IEC in 1950 [2]. Contributed to the development of the tokamak and the H-bomb.

Introduction

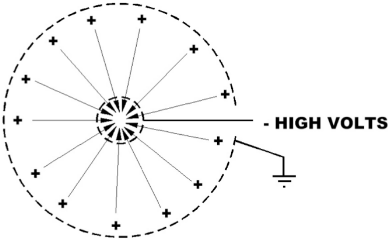


Figure: The electric potential in a Farnsworth-Hirsch fusor [3, 4, 5, 6]. The picture is from [7].

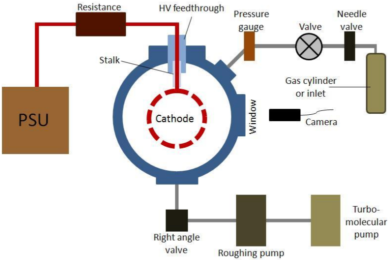


Figure: Schematics for a Farnsworth-Hirsch fusor from [8].

Introduction

IEC fusion research

- Kansai University, Kyoto University, Sydney University, Tokyo Institute of Technology, University of Illinois, University of Maryland, University of Wisconsin
- 21st Workshop on Fusion Neutron Sources and Applications (formerly Inertial Electrostatic Confinement Fusion Workshop), 17th – 18th December 2019, Kyoto University, Kyoto, Japan

Ammateur fusors

- Fusor.net is a forum devoted to building and developing fusors
- *The Neutron Club* is a list over *amateur* persons that have built a fusor and observed neutrons with it from fusion reactions
- Taylor Wilson built at the age of 14 a fusor producing neutrons through DD-fusion [9].

Introduction

Some of the most important fusion reactions for energy production:

$D + T \rightarrow$
$He(3,52\ MeV) + \mathbf{n}(14,07\ MeV)$

$D + D \rightarrow$
$^{3}He(0,82\ MeV) + \mathbf{n}(2,45\ MeV)$, 50 %
$T(1,01\ MeV) + p(3,02\ MeV)$, 50 %

$D + {}^{3}He \rightarrow$
$He(3,67\ MeV) + p(14,68\ MeV)$

$p + {}^{11}B \rightarrow$
$3He(8,68\ MeV)$

$^{3}He + {}^{3}He \rightarrow$
$He(12,86\ MeV) + 2p$

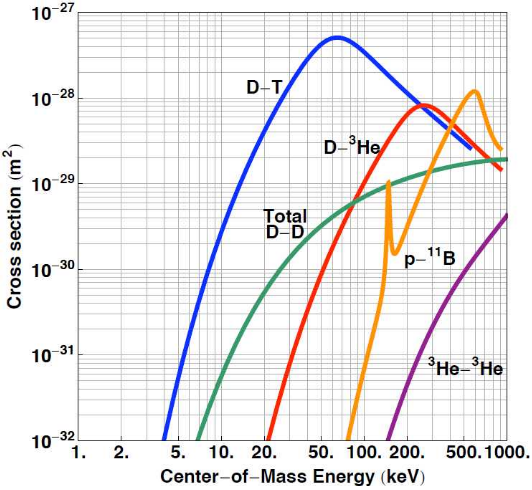
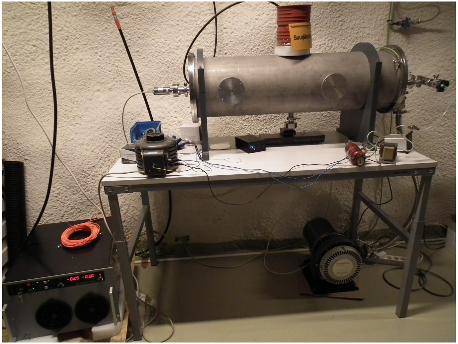


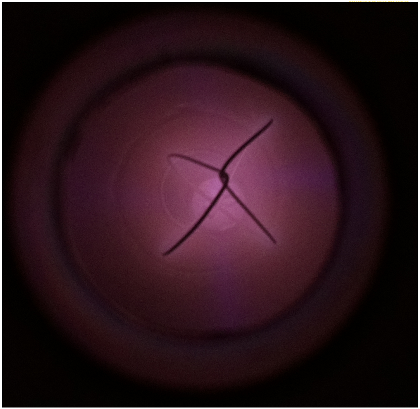
Figure: Cross sections as a function of center of mass energy for some of the most important fusion reactions [10]. (1 keV ≈ 8 MK)

Project goals

- The goal is to have the fusor remotely controlled for safety reasons
  - Location: Accelerator laboratory target hall cave inside the rock in Kumpula
  - Building access is restricted
  - Room access restricted by fence
  - Room surrounded by rock and tile walls, paraffin tiles to be put in place
- Use and develope open source software in this project
- Use Linux friendly inexpensive hardware
  - Raspberry Pi 3 Model B with a 8 Mpixel Sony IMX219PQ camera
    - Manual focus is preferred for viewing plasma
    - 8 Mpixel resolution is more than on a typical USB-webcam
    - Photographing can be automated with Linux scripts
  - LabJack U6 USB data aquisition (DAQ) device
  - Digilent Analog Discovery2: USB Oscilloscope, Logic Analyzer, Function generator
    - To be used as an Multichannel analysator for thermal neutron detection
- Goal 10^6 n/s from deuterium-deuterium fusion, should reach 10^7 n/s

Cylindrical test fusor





- Created air and He plasmas with a 105 cm long cylindrical test setup.
- Used only a loaned scroll pump Leybold SC 30 D specified to reach $1{\cdot}10^{-2}$ mbar, but in practice it could reach $1.44{\cdot}10^{-3}$ mbar.
- For color calibrating the Sony IMX219PQ camera we use the values given in [11].

Software development

Python drivers have been developed or are being developed for:

- Leybold TURBOVAC 90 iX turbo vacuum pump
- Technix 100 kV, 50 mA HV-power supply
- NorCal GVMP-2502-CF-S22-METRIC pneumatic valve
- `https://github.com/fkivela`

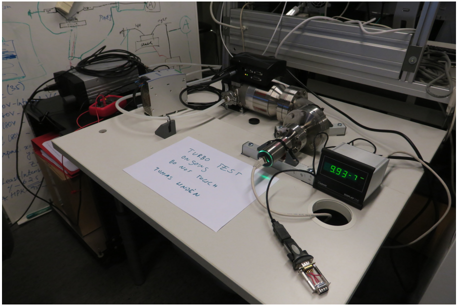


Figure: The turbo pump driver test setup at $9.93 \cdot 10^{-7}$ mbar.

Spherical fusor hardware

- Vacuum chamber: 10 port, 50,8 cm diameter steel double walled water cooled [8]
- Lead-glass CF63 viewport for plasma viewing
- Leybold DIVAC 1.4HV3C 12LE13520V foil pump
- Leybold TURBOVAC 90 iX turbo pump
- Pressure gauges: Leybold PTR90 CF, Edwards AGP-M-NW16 D021-71-000
- Gas input: Thermo valve, manual valves
- HV-power supply: Technix SR100kV-5kW, 100 kV, 50 mA
  - The HV-power supply can be used remotely over an serial optical link
- GenVolt 198,7 kΩ, 180 kV, 500 W series resistor
- 100 kV Vacom HV feedtrough CF100-HV100R-1-CE-SS40
- HV-stalk: Quartz glass
- Control PC: Recycled Core i5, CentOS 7 Linux
- USB optoinsulator between PC and USB-hub
- A ^{3}He-tube has been tested with a neutron source

Spherical fusor hardware

Current status and next steps

- Assembling and testing spherical fusor hardware
- Soon ready for vacuum tests
- A 93 mm diameter 3-ring cathode has been laser welded of W75%Re25% 0.762 mm wire
- Installation of the cathode, stalk and HV feedtrough will allow first plasma
- Finalize safety systems, radiation detectors
- Measure radiation levels
- Apply for operational permission from STUK
- Produce neutrons with deuterium-deuterium fusion
- Use in teaching
- Optimize neutron production
- Add more instrumentation
- Confluence project page [12]

Current status and next steps

Figure: The Technix 100 kV HV power supply.

Figure: The fusor vacuum chamber and control electronics.

References

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[7] Tom Ligon, *The World's Simplest Fusion Reactor, And How to Make It Work*

[8] E.C.G. Hermans, The Design and Optimization of an Inertial Electrostatic Confinement Fusion Device.

[9] Taylor Wilson Wikipedia page

[10] Fusion cross sections from the University of Wisconsin

[11] M. A. Pagnutti et. al., *Laying the foundation to use Raspberry Pi 3 V2 camera module imagery for scientific and engineering purposes.*

[12] Confluence page for the Helsinki fusor project

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