Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 19-20, 2022

Design and construction of pulsed magnetic mirror device

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1. Introduction

Recently, a new magnetic mirror device, KAIMIR (KAIST Mirror) was designed and constructed at KAIST. The chamber is composed of three parts, source, center and expander. Plasma gun[1] is utilized as the plasma source and its power is supplied through Pulse Forming Network (PFN)[2] system. Initial plasma was achieved and its density and temperature levels at source region were measured with triple Langmuir probe. KAIMIR will be a versatile device for plasma physics and engineering study. Using KAIMIR, we will study mirror plasma physics such as the effect of electrode biasing and vortex confinement[3,4]. This device will be also utilized for basic plasma physics experiments, including wave particle interactions in plasmas[5]. In addition, dense plasmas generated by plasma gun will allow us to conduct divertor detachment[6] experiments for fusion research with additional gas puffing system.

2. Design of pulsed plasma system

2.1. Vacuum chamber design

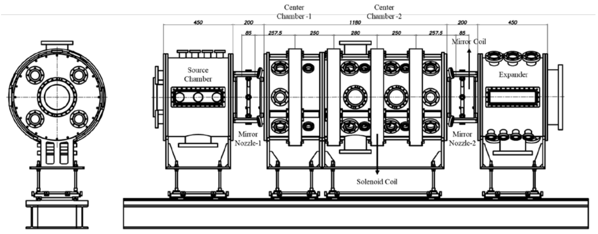

Figure 1. schematics of the vacuum chamber

Overall vacuum chamber consists of source, center and expander. Total size of the chamber is 0.65m diameter and 2.48m length. Each part is able to disassemble from the system if necessary. In the source chamber, plasma will be generated from the plasma gun. A turbo molecular pump is also installed at the source chamber to quickly extract neutral gas injected from the plasma gun. Center chamber connects source chamber and expander with mirror nozzle. Single Convection gauge and two Baratron gauges measure low vacuum pressure above 5×10^{-4} Torr at the center chamber. Ion gauge is also installed to check high vacuum pressure inside the chamber. Base pressure of the chamber is below 3×10^{-7} Torr. Collector is placed in the expander chamber and is electrically isolated from the chamber. Plasma gun and collector are movable to change their axial locations.

2.2. Magnetic field configuration

Magnetic coils are located at z=±730mm, ±645mm for mirror coils, and ±388mm, ±138mm for solenoid coils, where z=0 is at the center of the chamber. Mirror coil has 360 number of turns and solenoid has 120 turns. Coils are made of rectangular copper wire (1.8mm x 3mm), and their resistance and inductance values are 0.746Ω, 15.31mH for solenoid coils and 1.026Ω, 43.07mH for mirror coils. Series connected ultra-capacitors (2000F, 2.7V, ×60 for solenoid coil, ×80 for mirror coil) are used for coil power system. Charged coil power is controlled by IGBT module with maximum rating 600V, 800A. Due to self-inductance of the coil, the time required to reach the maximum steady current value is ~ 100ms for mirror coils and 50ms for solenoid coils. We therefore need to turn on mirror coils about 50ms prior to turning on solenoid coils to make both coil currents reach the peak at the same time. Maximum applicable current, restricted by the current power system, to the coil is 150A for each coil, which generates magnetic field 0.44T at mirror region and 0.081T at solenoid region.

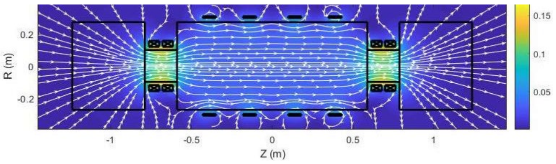

Figure 2. Magnetic field configuration simulation (150A)

2.3. Pulse forming network system

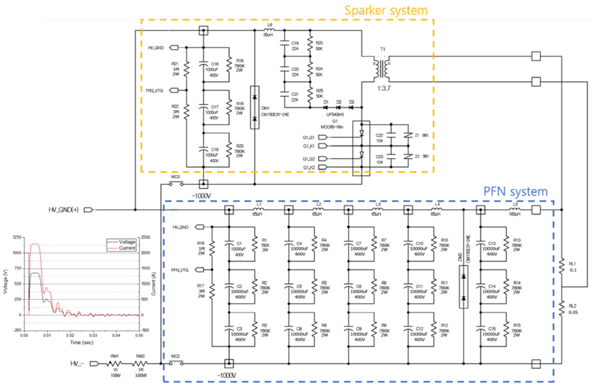

Figure 3. PFN system circuit, PFN voltage / current waveform

In order to reduce the required voltage of PFN system for plasma gun, sparker circuit is added between PFN and plasma gun. Applying sudden high voltage from sparker circuit including sparker capacitor and transformer (max 4000V in 100us), breakdown will be occurred inside the gun. Then gun plasma will be sustained by PFN power. The electric power charged to the PFN system rapidly inject ~2kA current through the plasma column with pulse duration 5ms.

2.4. Data acquisition and control system

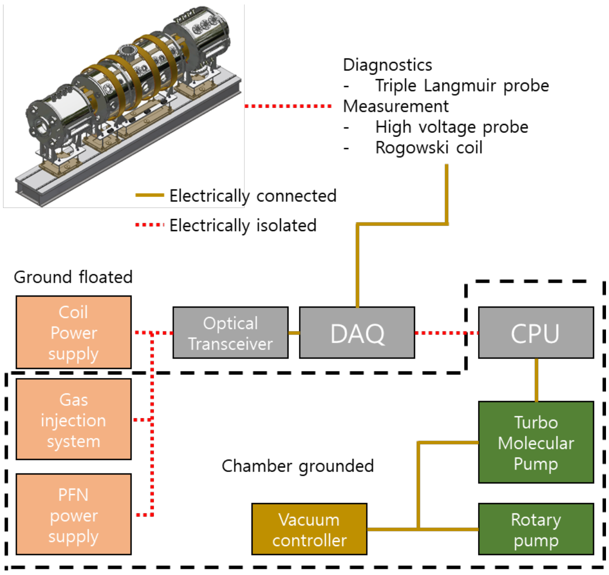

Figure 4. DAQ system and diagnostics

Data acquisition (DAQ) and control system for KAIMIR consists of single PXI chassis, PXI controller, 4 multipurpose module and 2 PXI oscilloscopes. Software program for the DAQ and control system was written by Labview. This software is run in the computer optically connected to DAQ system. DAQ generates digital outputs to optical transceiver which transfers switching signals to IGBT drivers. DAQ system also receives signals from many diagnostics. Triple Langmuir probe measures plasma density and temperature, and high voltage probe sends voltage of the particular PFN circuit points with time. Rogowski coil measures current flowing through the plasma gun or other cable lines.

3. Initial plasma experiment

3.1. Experimental conditions

Once construction of KAIMIR was done, initial plasma was achieved. Base pressure in the initial plasma experiment was ~10^{-7} Torr. Argon gas was puffed during 200ms (t=100-300ms where t=0 is the time when the control software program is started) using Piezovalve right before plasma gun is triggered by sparker. Then, pressure increased up to ~10^{-3} Torr in a moment and decreases rapidly. IGBT switch of the magnetic coil was turned on at t=150ms, then it was off at t=450ms. The current flowing in the coil during the discharge was 60A for both mirror and solenoid coils and generated magnetic field is 177mT at the mirror and 32mT at the center. Plasma gun is triggered at 300ms and discharges plasma for ~160ms. The reason why discharge duration increased from 5ms to 160ms is likely due to larger inductance and resistance of the sparker circuit's transformer than expected.

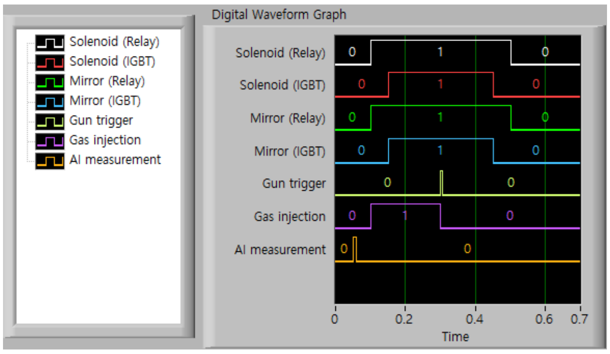

Figure 5. Control software digital output trigger timing

3.2. Triple Langmuir probe design and measurement

Langmuir probe is an effective tool to measure basic plasma parameters. From the I-V characteristic curve generated by the probe, we can get plasma temperature, density and potential. However, it is difficult to apply this diagnostic to transient plasmas. Triple Langmuir probe (TLP) and sweeping Langmuir probe are two major ways to overcome the temporal resolution problem of the probe[7]. Since our plasma gun system was supposed to generate 5ms plasma discharge, triple Langmuir probe, which has higher time resolution compare to sweeping probe, was selected for the probe system.

TLP consists of metal tip, alumina tube and SUS tube. Tungsten was used as a metal tip since it has high heat tolerance. It has diameter 0.3mm and length 10mm. Alumina tube has 4 hole and small tip is fixed to each hole in order to adjust small tungsten tip. Alumina tube has 100mm length, which is double of the expected plasma diameter. SUS tube is glued to the end of the alumina tube with Torr seal. Tungsten tip is connected with thin wire at SUS tube and is linked to BNC line of vacuum feedthrough.

Plasma parameters were measured at the center of the mirror nozzle region. The plasma density was ~10^{20}m^{-3} initially, then decreased exponentially during 160ms. Plasma temperature was ~3eV. Other diagnostics such as optical emission spectroscopy, single Langmuir probe, and interferometry, should be applied to verify the TLP measurement.

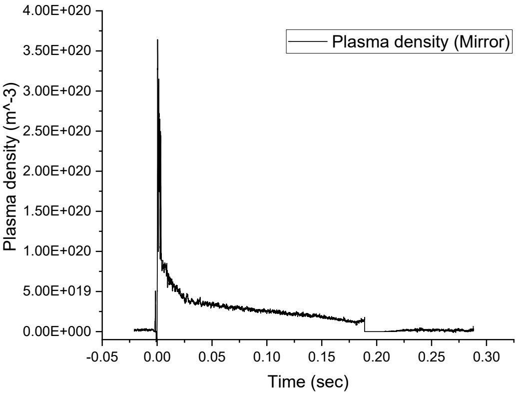

Figure 6. Plasma density at center of the mirror nozzle(source)

4. Summary

New pulsed magnetic mirror plasma device, KAIMIR was built in KAIST. Arc plasma gun was applied as plasma source and electromagnetic coils generate magnetic mirror geometry that confines plasma. System control and data acquisition were done by DAQ. Initial plasma was achieved and its density and temperature were ~$10^{20}m^{-3}$, 3eV at the moment when the plasma was generated, from triple probe measurements.

4. Acknowledgments

This work is supported by research fund (program) for new faculty settlement funded by Korea Advanced Institute of Science & Technology (KAIST) (G04200005).

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