Design of a Solenoid Magnet for a Microwave Ion Source

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1. Introduction

A microwave ion source has many advantages, such as long-life time, low emittance, high brightness, and compactness. Also it is a big merit that 2.45GHz rf systems are easily available and inexpensive. Due to the reasons microwave ion sources are very attractive for industrial applications.

But microwave ion sources need a solenoid magnet which is usually an electromagnet with a DC current power supply. The electromagnet solenoids of microwave ion sources can be installed in two methods. The first method is to use isolation transformer to supply electrical power to DC current power supply for the magnets. In this case the magnet is compact because it has the same potential with the extraction voltage. The second method is to put an electrical insulator, such as G10, between ion sources and magnets. In this case the solenoid magnet is bigger than one in the first method, especially for higher extraction voltage, because the space for the insulator is required.

Permanent magnets can be a good candidate to make microwave ion source more compact. But it is difficult to control the magnetic field profile and the magnetic flux density for the permanent magnet solenoids. Due to the reason, in the case that the best performances in many operating conditions should be achieved by adjusting the profile and strength of the solenoid, electromagnet is better than permanent magnet. But in the case of industrial applications where operating conditions is usually fixed and the compactness is required, permanent magnet is better choice to build an ion source.

2. Design

An electromagnet solenoid consists of an azimuthal winding of coils with an iron yoke which makes the solenoid compact and efficient. But a permanent magnet solenoid consists of two permanent ring magnets on the both ends of a cylindrical yoke. The magnetization directions of the ring magnets are radial, one is inward and the other is outward. The material of the permanent magnets is NdFeB which is inexpensive and easily available, and has large maximum energy product.

The geometry of the permanent magnet solenoid was determined to replace the electromagnet solenoid of the ion source which is being developed for a proton linear accelerator. PANDIRA code was used to simulate the magnetic field of the permanent magnet. The magnet field distribution is shown in Figure 1.

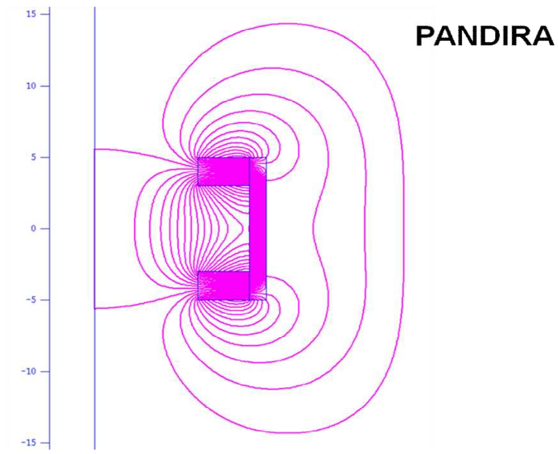

Fig. 1. Magnetic field in permanent magnet solenoid.

The magnetic field of permanent magnet solenoid (PM) along the center has a different profile from the one of an electromagnet solenoid (EM) as shown in Figure 2. If the permanent magnet solenoid has the same axial length with an electromagnet solenoid, the uniform field region for the permanent magnet solenoid is narrower than the one for the electromagnet solenoid.

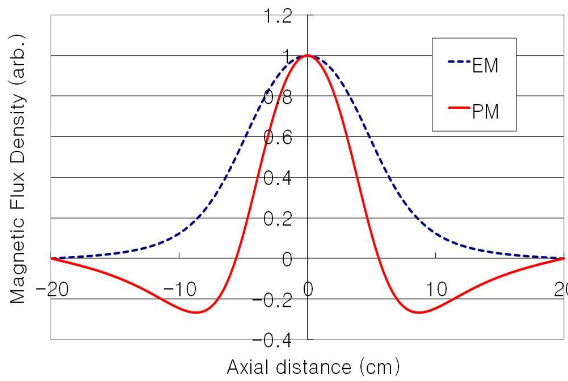

Fig. 2. Axial magnetic field profile for EM and PM.

For an enough uniform field region where the plasma chamber is located, the permanent magnet solenoid should be longer than the electromagnet solenoid. The magnetic field profiles in radial direction are similar as shown in Figure 3.

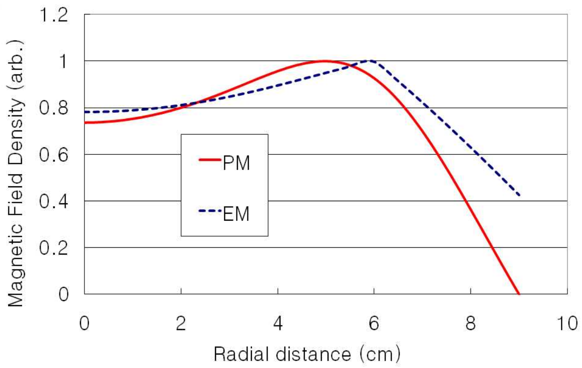

Fig. 3. Axial magnetic field profile in radial direction for EM and PM.

2. Fabrication

Figure 4 shows the permanent magnet solenoid fabricated with NdFeB permanent magnets and a iron yoke. A permanent magnet block, which is easily available, measures 1cm x 2cm x 2cm. The permanent magnets of three blocks are arrayed in 15 rows with equal spacing for uniform magnetic field.

Fig. 4. Fabricated permanent magnet solenoid.

Figure 5 shows the measured magnetic flux density along z axis in the plasma chamber which is 10cm long in z direction by using a hall probe. The position of z=0 is the location of the plasma electrode for the beam extraction and the position of z=-80 is the location of the rf window facing plasma.

The microwave ion source with an electro magnet solenoid was modified to install the permanent magnet solenoid for the experiment. Figure 6 shows the installed permanent magnet solenoid to the microwave ion source. Argon plasma can be generated easily without any ignition method. At $3x10^{-6}$ torr more than 90% of forward rf power to the ion source was absorbed. Argon ion beam was extracted up to 7mA with 600W rf power at 40kV extraction voltage.

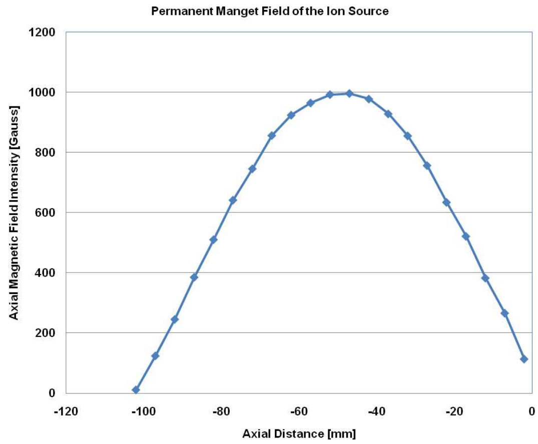

Fig. 5. Axial magnetic flux density (Bz) of the permanent magnet.

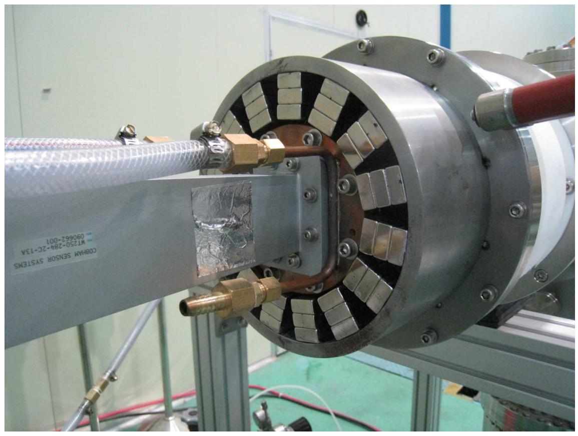

Fig. 6. Permanent magnet solenoid installed on the ion source.

3. Conclusions

A permanent magnet solenoid for a microwave ion source was designed and fabricated. It was installed in the experimental test setup with a 2kW 2.45GHz rf generator. Using a permanent magnet solenoid instead of an electromagnet solenoid, we can reduce the size of the ion source and the electric power consumption.

ACKNOWLEDGMENT

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