ANALYSIS OF THE PLASMA CHARACTERISTICS FOR BEAM CURRENT OPTIMIZATION FOR TR-13 CYCLOTRON ION SOURCE

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Abstract

There is a TR-13 cyclotron that extracts energy of 13 MeV protons which is located in Sungkyunkwan University. The researchers in this laboratory were eager to improve the technical problems of the components and finally optimize the beam profile. The finally extracted beam current is critically depends on the initially extracted beam from the Ion Source Injection System (ISIS). The ISIS is composed of several electrical instruments. The voltage or current which is applied to these components can affect the finally extracted beam profile. However, the original values for the input voltage or current is almost fixed to special values that had been written in the operation manual. It means that the bad condition of this cyclotron cannot be matched for these values which had been conducted in the best condition of the operation. So, by using the programmable logic controller (PLC), it is possible to use varying inputs in various conditions, and the beam current is able to be stabilized much better than applying the constant input values. Finally, this paper would show the tendency of the plasma generation in terms of modulating the applying input values which occurs inside the ion source chamber. It represents the plasma characteristics that critically influence the beam current.

INTRODUCTION

TR-13 cyclotron is originally manufactured from TRIUMF company in Canada. IT accelerator engineering centre in Sungkyunkwan University tried to manage this cyclotron's for engineering research.

One of the most significant factors for the performance of the accelerator is the extracted beam current. The beam current depends on lots of background environments such as the vacuum level, stability of the input/output power, or gas injection and so on. And also the firstly extracted beam from the ion source chamber can be the primary points for intensifying the finally extracted beam current. Since the last beam profile is strongly affected by the initially extracted beam from the ion source, the beam flows in the ion source injection system should be considered weightily. The ion source injection system consists of ion source, steering magnets, quadruple magnets, inflector, etc. Though, the plasma generation can be the systemic function for the whole structure of the ion source injection system [1, 2].

In the ion source chamber, negative hydrogen ion generating reaction is performed under several conditions. The simple procedures follows: hydrogen gas injection, electron emission form the high current filament, arc discharge between hydrogen gas and the electrons, plasma region displacement, ion beam extraction. Within these procedures, the operator can manipulate many conditions in the ion source chamber. Briefly, the negative hydrogen ion beam generation is dependent to vacuum level, arc discharge, electron emission, plasma potential, and extraction voltage which is able to be controlled by PLC system. Thus, this paper will represents the feature inside the ion source chamber on the part of plasma characteristics [4].

EXPERIMENTS

Experiments with variety of conditions had been conducted, and it shows many specific tendencies. Every electronical devices are remotely controlled by PLC unit.

Mass flow controller (MFC) in this system is a device that control the flowing amount of the neutral hydrogen gas that coming from the gas source to the ion source chamber. It can decide the vacuum level in the ion source chamber and thus the amount of the hydrogen particles to be reacted with electrons can be controlled [3].

The controlling range of the hydrogen has injection is 0~10 SCCM and the whole range is covered for the experiments.

Figure 1 features the operation of the power supplies (Arc P/S, Filament P/S, Plasma P/S) within the condition of arc voltage : 100V, arc current : 2A, plasma potential : 3.1V), without injecting the hydrogen gas. In the experiments, only the arc current ,the plasma potential, steering magnet and the extraction lens voltage had been changed. The arc current is decided by the amount of the generated plasma, and plasma potential corresponds to the displacement of the plasma region in the ion source chamber. And they determine the total amount of the extracted beam. The plasma current and the extractor lens current of each situations had been observed in this experiment. Conclusively, the graphs show that in order to increase the beam current extracted from the ion source, the extractor lens current should not reach to saturation level earlier.

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Figure 1: Ion source power supplying unit (Xantrex).

RESULTS

MFC & Power Supply Control

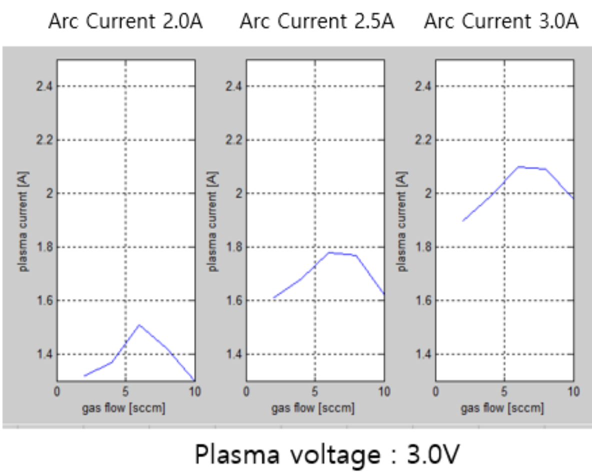

Figure 2: Plasma current with MFC control and various arc current in plasma potential 3.0V.

Figure 2 shows several suggestions. The gas injection level is optimized around 6~8 SCCM that makes the quantity of the plasma maximized. And also the arc current works same as the function of the gas injection level. The vacuum level of the ion source chamber had been increased linearly from 1.3E^{-6} mbar to 2.8E^{-6} mbar in step size of 5E^{-7} when the hydrogen injection had been completed.

There can be several assumption with Figure 3 and 4. From Figure 3 the extraction current and bias current show keep going down since the bunch of the beam in the plasma get closer to the lens electrodes that makes the power supply output flows into the plasma region. And that is the reason why the extraction power supply shows constant current mode. Also, the ionized subject, plasma, makes the common ground of the whole power supply to be connected with short circuit. Whenever the flowing current exceeds the limitation of the power supply output current, then the beam cannot be extracted anymore as like shown in the right side graph of Figure 4 (saturated beam current).

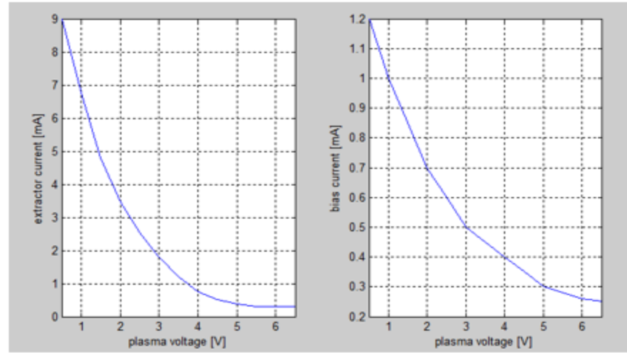

Figure 3: Extractor lens current and bias power supply current with plasma voltage control.

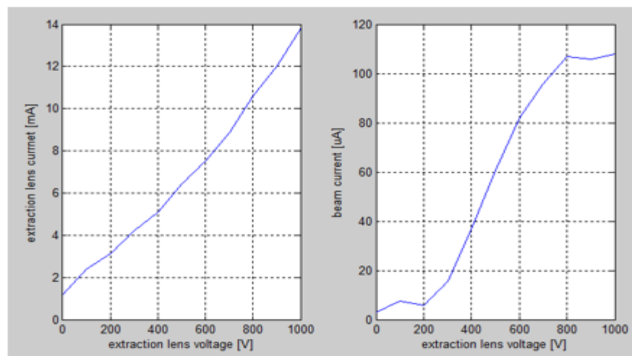

Figure 4: Extractor lens current and beam current with extractor lens voltage control.

Ion Source Lens Modelling

Table 1 shows the extraction voltages for constant current mode of the extractor lens power supply and the extraction current for the voltage value of extractor lens power supply is zero with increasing plasma potential values. The maximum output of the extractor lens power supply is 5kV, 15mA. Constant current mode of the power supply means that the beam current cannot be extracted more than the maximum power supply output. So as to increase the beam current, the extraction power supply must not reach to maximum output level as mentioned above.

Table 1: Extractor Lens CC Mode Experiment Result

Plasma voltage [V]	Plasma current [A]	Extraction voltage when CC mode starts [V]	Extraction current when extraction voltage is 0V [mA]
0.0	0.43	0	15, CC mode
0.4	0.43	0	15, CC mode
0.8	0.43	0	15, CC mode
1.2	0.43	0	15, CC mode
1.6	0.43	0	15, CC mode
2.0	0.43	0	15, CC mode
2.4	0.43	0	15, CC mode

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2.8	0.53	35	13.35
3.2	0.77	40	9.75
3.6	1.03	45	7.5
4.0	1.27	60	5.7
4.4	1.43	75	4.35
4.8	1.58	105	2.85
5.2	1.78	185	1.35
5.6	1.92	255	0.585
6.0	2.05	295	0.405
6.4	2.12	300	0.315
6.8	2.14	300	0.255
7.2	2.18	295	0.225
7.6	2.19	305	0.180
8.0	2.23	305	0.150

Moreover, CST studio simulation result shows the electric potential tendency nearby the plasma lens and the extractor lens [5]. This analysis would represents that the extracted beam can be distorted in unexpected way whenever the plasma region is not well created in the ion source chamber which can cause to large amount of bema loss in front of the faraday cup. In Figure 5 the electric field shows like shape of an arc. It means the direction of the negative hydrogen ion beam would be curved in diverging way. Then the beam will bump into the electrode to make CC mode. Whenever the starting point of the beam is adjusted to another point, the beam will not collide into the unexpected location. That means the plasma displacement, the plasma potential, is the important parameter to be considered.

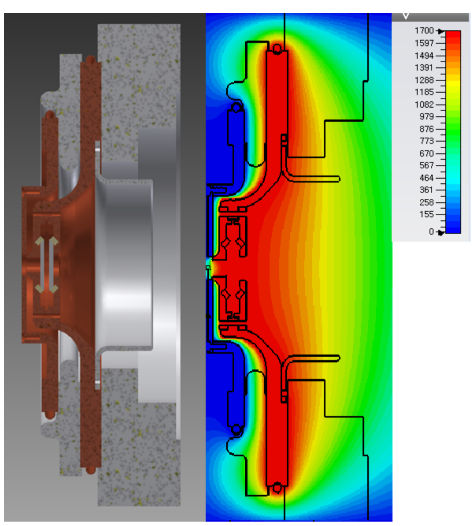

Figure 5: Electric potential analysis of the plasma & extractor lens CST studio E-solver.

DISCUSSION & CONCLUSION

The ion source operation for the TR-13 cyclotron requires many sophisticated experimental environments. Many factors such as vacuum level, power supply output, or perhaps humidity should be regarded as the main causes for good beam profiles. The importance of the applying voltages on the extractor and plasma lens are written in this paper. It was shown that large amount of plasma have nothing to do with the beam current, but the exact position of the plasma region might influence the extracted beam profile. And the tool for finding the optimized distance between the plasma region and the plasma lens can be determined by the extractor lens current. Additionally, there are subsidiary effects of the arc current or any other reasons such as SCCM level can also be the significant keys to make the beam current better.

After putting together the overall results in Table1, Figure 2, Figure 3, and Figure 4, finally there shows some obvious disposition of the beam profile with respect to applying inputs.

1. Adjust the plasma voltage to modulate the displacement of the plasma region where the beam initially start.
2. Increase the arc current considering with the injection of gas flow.
3. Take account for the load resistance of the extractor lens power supply to make the extraction current weakly.

Each sentences are dominant for increasing the beam current. After improving the electrical instruments to brand-new ones or find the optimized values for ion source operation, the whole performance will be upgraded.

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