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DESIGN OF ACCELERATOR MASS SPECTROMETER BASED ON CYCLOTRON

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Abstract

In this paper, we present a cyclotron accelerator mass spectrometry system based on artificial intelligence. Cyclotron based AMS system are consist of cyclotron, ion source, RF buncher, dipole magnet and triplet quadrupole, detector. This Cyclotron based AMS system optimized the detection efficiency of $14C^-$ particles through artificial intelligence algorithms. Cyclotron was designed with a mass resolution of 5000, AVF electromagnet with 4 sectors. RF system was designed as RLC circuit consisting of Dee of which angle is 20 degrees. The stripping method was used of extraction. The ion source of AMS uses Cs sputtering source with Einzel lens and RF buncher. In this system, AI algorithm is applied to the detection and analysis algorithm through artificial neural network development to overcome the mass resolution time and precision by $14C^-$ sample number. The AMS has been designed and detailed hardware production is underway, and the system will be integrated in 2020 to carry out the mass decomposition experiment.

INTRODUCTION

In accelerator mass spectrometry, tandem accelerator is mainly used. Sungkyunkwan University developed cyclotron-based AMS cyclotron see Fig. 1. The advantage of the cyclotron-based AMS system is reducing the size and cost of the entire system. because cyclotron itself acts to separate the particles [1].

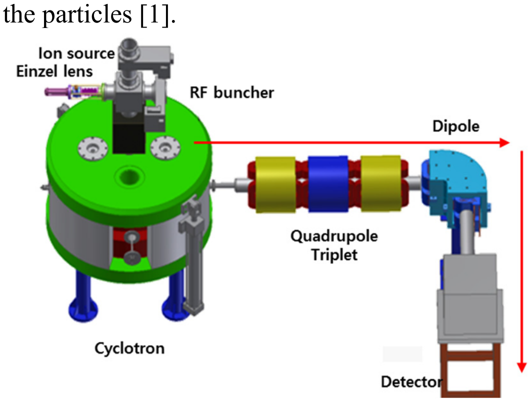

Figure 1: 3D drawings of Accelerator Mass Spectrometry based on cyclotron.

The tandem type accelerator is an electrostatic type, and the finally discharged particles are DC type. In the case of cyclotron, the electric field of RF emits the emissive particles in AC form. So Relatively fewer samples than static AMS. To solve this problem, we add artificial intelligence to increase the accuracy of the analysis.

The 3D drawing of cyclotron for AMS is shown in Fig. 2 and specification table of AMS cyclotron is shown as Table 1. This cyclotron is for accelerating carbon-14 beam.

DESIGN AND SYSTEM DESCRIPTION

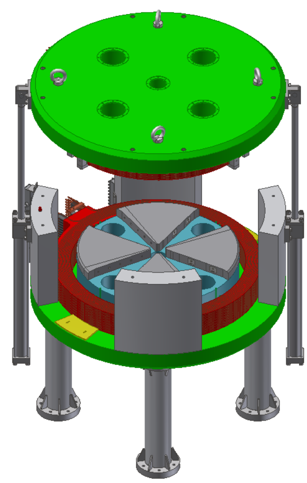

Figure 2: 3D drawings of cyclotron for AMS.

Table 1: AMS Cyclotron Magnet Specification

Parameter	Value
Maximum energy	200 keV
Beam species	Carbon-14 negative
Ion source	Cs sputtering
Number of sectors	4
Hill angle	60°
Valley angle	40°
Pole radius	0.510 m
Extraction radius	0.453 m
Hill / Valley gap	0.25
Harmonic number	10
Radio frequency	5.8 MHz
Radial tune	~ 1.01
Vertical tune	0.4
B-field (min., max.)	0.137, 0.687 T

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Maximum energy of carbon-14 beam is 200 keV. We select the harmonic number of 10, turn number is 159 turns. Because of this value is relate with mass resolution. Mass resolution is very important value at the AMS system. The mass resolution of AMS cyclotron is about 5000 [2]. The cyclotron has been manufactured and is currently undergoing magnetic field measurement and shimming.

The 3D model of magnet 3D model of magnetic field measurement instrumentation for AMS cyclotron is shown in Fig. 3. The hall sensor probe was on the bracket (1). It will rotate mid-plane of magnet. The step motor (2) was installed at the center of magnet, which is connected with rotation jig directly. The Rotation plate (3) prevent the rotation jig form tilting when magnetic field measurement instrumentation operates. The hall probe sensor had been moved by spur gear (4) and ratchet gear (5) along the radial direction. The Linear guide (6) supports hall probe sensor.

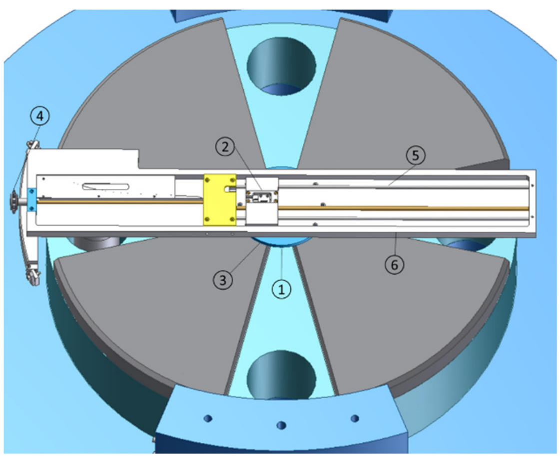

Figure 3: 3D drawing of magnetic field measurement system for AMS cyclotron.

The 3D drawings of Dee electrode are shown in Fig. 4 and specification table of Dee electrode is shown as Table 2.

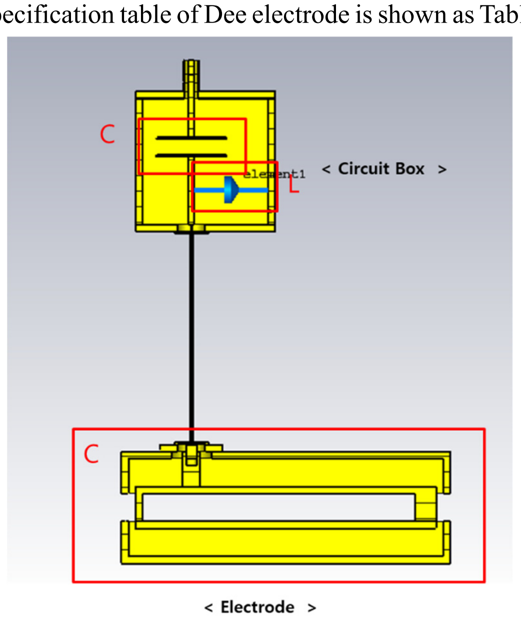

Figure 4: 3D drawing of Dee electrode for AMS cyclotron.

We designed a circuit box to match impedance and frequency. The circuit box is composed of capacitance and inductance. Approximate frequencies are set through inductance, impedance and detail frequency is set through capacitance [3].

We designed each components of the accelerator mass spectrometry beam line. Each component has been manufactured and is currently being tested for each part. Each component. Each component is shown in Figs. 5-7.

Table 2: Dee Electrode Specification

Parameter	Value
Vacc	300 V
Frequency	5.8 MHz
Accelerating distance	138 - 453 mm
Dee angle	20°
Number of Dee	2

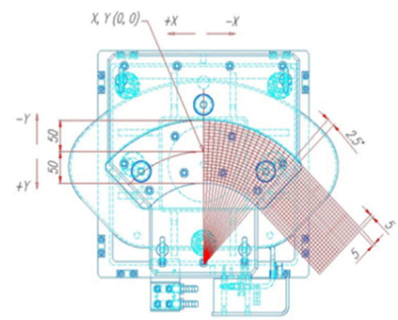
Figure: 5 Dipole magnet for AMS beamline.

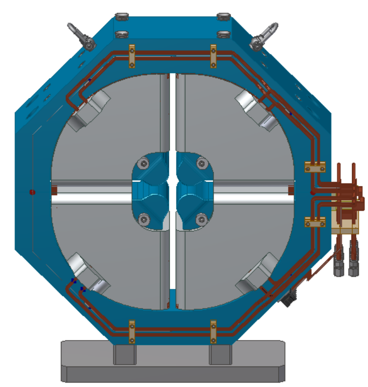
Figure 6: Quadrupole magnet for AMS beamline.

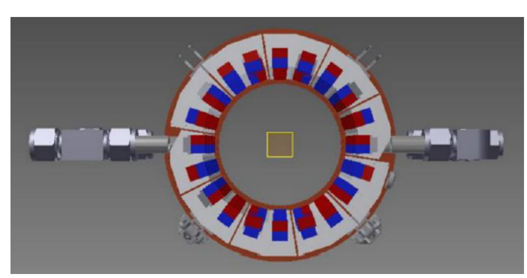
Figure 7: Ion source for AMS cyclotron.

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Compared to tandem accelerators, acceleration particles are relatively small. Figure 8 is a block diagram of the accelerator control system based on neural network. The cyclotron control system for AMS uses data acquisition and logging of the accelerator drive parameters and combines this data with machine learning technology for cyclotron tuning and detector particle sorting. In order to implement the machine learning-based cyclotron control algorithm, the resonance point variation is simulated by the RLC model and the acceleration cavity output voltage is constructed in the form of time domain simulation. In addition, Normal distribution is analyzed by reflecting random noise components such as thermal noise amplifier noise [4].

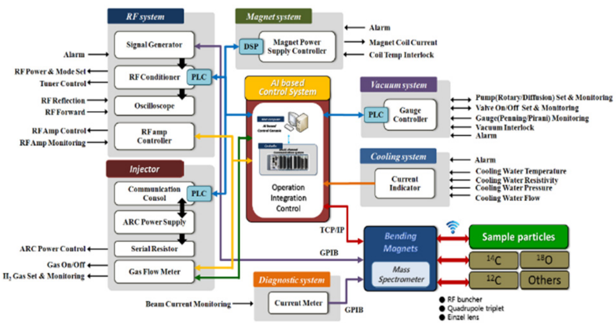

Figure 8: AI-based accelerator control system configuration diagram.

RESULTS AND DISCUSSIONS

A magnetic field measuring device for cyclotron for AMS was developed. The magnetic field 3D mapping was performed using the developed measurement instrument and the result is shown in Fig. 9.

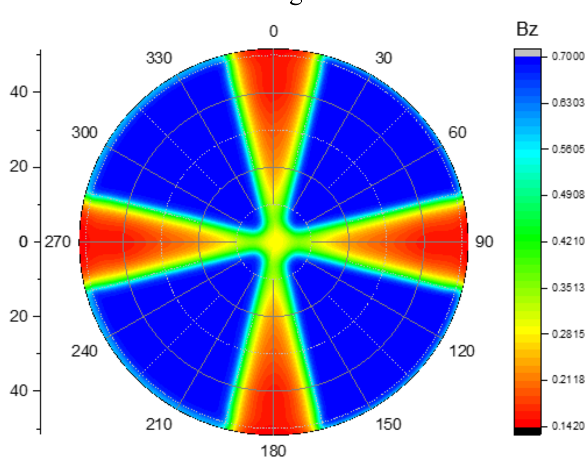

Figure 9: Magnetic field mapping data of AMS cyclotron.

The control system was constructed using the Adventure Actor Cricket method, which is a kind of reinforcement learning, and the learning was conducted by finding a policy that maximizes the reward.

The neural network was implemented inside the NI CRIO controller and we could see it converge around the resonance point, as shown in Fig. 10.

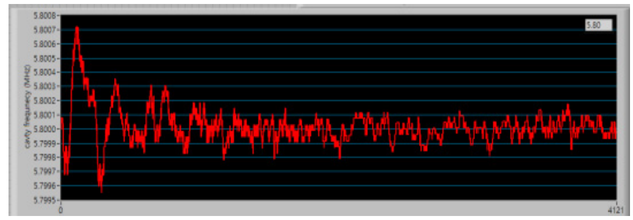

Figure 10: A2C resonance control learning process at 5.8 MHz constant resonance point.

CONCLUSION

We have developed a cyclotron based AMS system. Each component has been developed and tested Cyclotron-based AMS systems are currently under test. It also aims to operate in 2020. Based on machine learning, we develop an AI system that improves particle extraction accuracy and controls optimal isochronous magnetic field and RF frequency according to particle type.

ACKNOWLEDGMENT

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