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DEVELOPMENT OF REAL-TIME MASS ANALYSIS SYSTEM WITH PERMANENT MAGNET FOR ION BEAM

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Abstract

In order to analyze time variation of the ion species in a pulse, we are developing a mass analysis system that has multiple collector electrodes to detect several ion species simultaneously. Strong permanent magnets can generate 1T magnetic field and the size of the analyzing magnet system can be compact. The detected signals are scanned by a fast multiplexer. The scanning rate is 2 MHz, so that all electrode signals of the 16 channels are scanned in 8 μs period. In this paper, details of the design of the analysis system, and preliminary beam extraction test results with prototype of the system are described.

INTRODUCTION

As part of development of a small neutron source based on proton linear accelerator, a compact Electron Cyclotron Resonance (ECR) H^+ ion source for extracting proton beam is under development [1]. In the ECR ion source, not only H^+ but also molecular ions (H_2^+ and H_3^+) are generated at the same time. Because the accelerator system can accept H^+, the H^+ fraction of the extracted beam should be as high as possible, which requires optimization of many parameters (magnetic field distribution, gas pressure, microwave power, etc.). For this, it is necessary to analyze the proportion of ion species in the extracted beam during the optimization of the parameter to increase the proportion of H^+. Momentum analyzers using a magnetic field or a Wien filter had been used so far, but a slow scanning measurement for the ion species was time-consuming and inefficient. In order to improve this problem, a quick scan type mass analysis system using permanent magnets is under development.

REAL-TIME MASS ANALYSIS SYSTEM

In this analysis system, the beam extracted from the ion source goes through the magnetic field generated by the analyzing magnet. Because of the difference in the mass-to-charge ratio of each ion contained in the beam, the trajectory of each ion in the magnetic field depends on the ratio. Therefore, by arranging multiple electrodes, it is possible to simultaneously detect ion species having different mass to charge ratios (see Fig. 1). A collimator is install at the entrance of the analyzer to keep the analyzing resolution. There is a hole at the back side of the system so that the plasma in the ion source can be observed from the downstream through the analyzing magnet. Charged particles go to corresponding electrode, and currents can be detected. The currents from the electrodes are collected by the 16 channel fast multiplexer installed under the electrodes, which is located inside the vacuum side and a multiplexed signal is transferred to the outside.

The analyzer can be installed just after the extraction electrode of the ion source, and can be evacuated from the beam line by retracting the analyzer body driven through the side port mechanically. Figure 2 shows schematic drawing of the analysis system located just after the ion source.

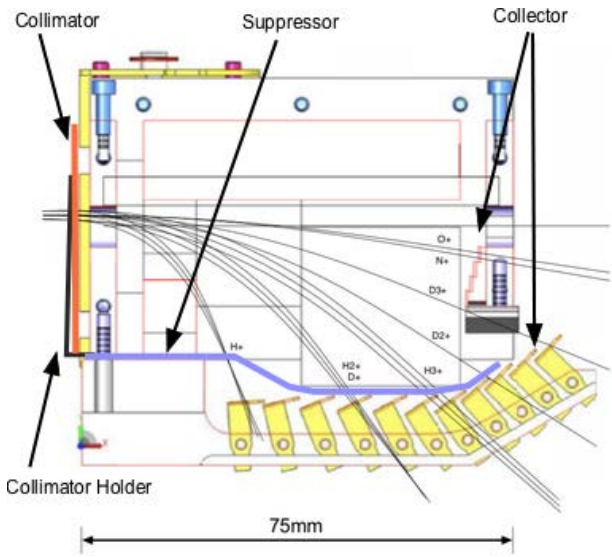

Figure 1: Cross section on the beam trajectory plane. Beam is analyzed by the magnetic field generated by the permanent magnets and detected by the multiple collector electrodes separately.

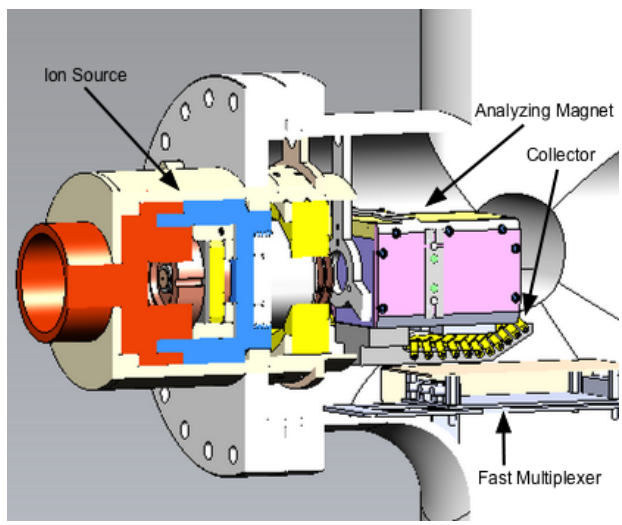

Figure 2: Schematic drawing of the analysis system. The compact analyzer can be installed directly after the ion source. The signals are scanned by the fast multiplexer and a multiplexed signal is transmitted to the outside.

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Analyzing Magnet

Since there is not much space in the ion source test bench, it was necessary to reduce the analyzer size as much as possible. For this reason, NdFeB magnets with a high magnetic flux density among types of permanent magnets was adopted as the magnet part. By adopting NdFeB magnets, the analyzer can be installed in the limited space. Using the two-dimensional magneto static calculation code PANDIRA [2], the generated magnetic fields are calculated, and the iron width of the return yoke is designed so that the iron part is not magnetically saturated (see Fig. 3). The yoke material is the general-purpose magnetic stainless steel material SUS 430 for the convenience of obtaining and handling. The magnetic field distribution in the gap was calculated with the three-dimensional magnetic field calculation code RADIA [3] and the orbits of various ions were simulated using Mathematica [4]. Figure 4 shows the simulation results for the extraction voltage of 25 kV.

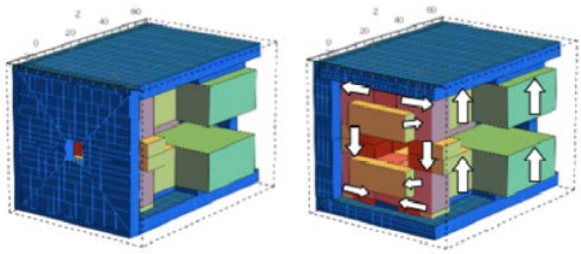

Figure 3: Schematic views of the analyzing magnet with and without (left/right) entrance field clamp. While the blue part is the return yoke, the rest is the magnet. Arrows indicate the directions of the easy axis of magnets.

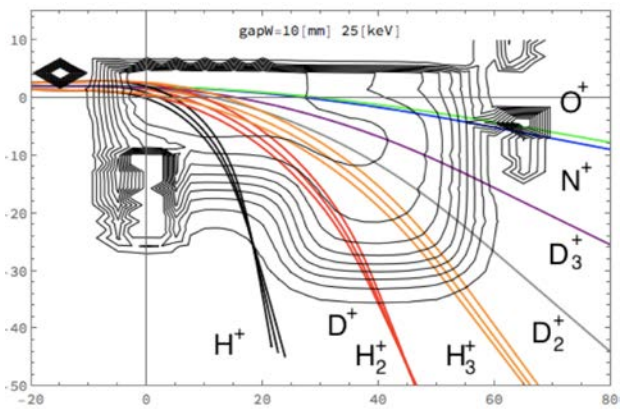

Figure 4: Simulation result of trajectories in the magnetic field calculated by RADIA (see text). Calculations were made for various ion species.

Electrodes

The analyzer has multiple electrodes, each having a different role (see Fig. 5).

- **Collimator and Holder**: On the front face of the analyzing magnet, a collimator fixed by the holding clip collimates the extracted ion beam. Currents of the charged particles stopped by the collimator are sent to one channel of the multiplexer through a conducting wire from the holder. Therefore, it is possible to know the total current extracted from the ion source by combining the currents from collimator and the collector.
- **Suppressor**: A suppressor electrode is located between the magnet and the collector electrode in order to suppress secondary electrons, by applying + 36 V.
- **Collector**: Following the simulation result of particle trajectories by Mathematica, we installed eleven main electrodes below the magnet part and four sub electrodes at the downstream; a total of 15 electrodes are installed. The main electrodes are at the positions for detecting ions from H^+ to D_3^+, and the sub electrodes are set at positions for detecting other heavy ions such as N^+, O^+.

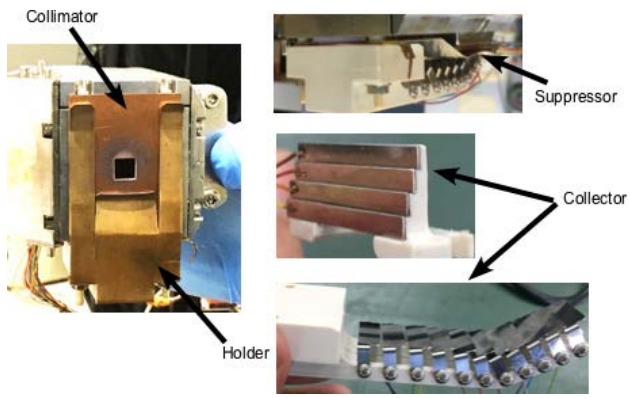

Figure 5: Collimator and Holder are shown at the left. Collectors (right center and bottom) and Suppressor (right top) electrodes.

Fast Multiplexer

The detected signals are scanned by a fast multiplexer in the vacuum area so that only three vacuum feed-through pins are required to operate this analyzer (see Fig. 6). The scanning rate is 2 MHz, which results in an 8 μs repetition period for all 16-channel electrode signals. This is sufficiently shorter than the operating time structure of the ion source.

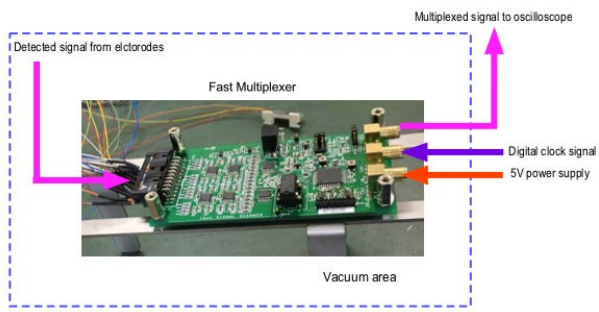

Figure 6: Only a power supply line, a digital clock signal line, and a multiplexed analog line are required.

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Screen Monitor

There is a turnable screen monitor coated with ZnS on the side of the magnet part (see Fig. 7). When ZnS is irradiated with an ion beam, yellow green fluorescence is emitted. As a result, the approximate profile of the beam can be observed.

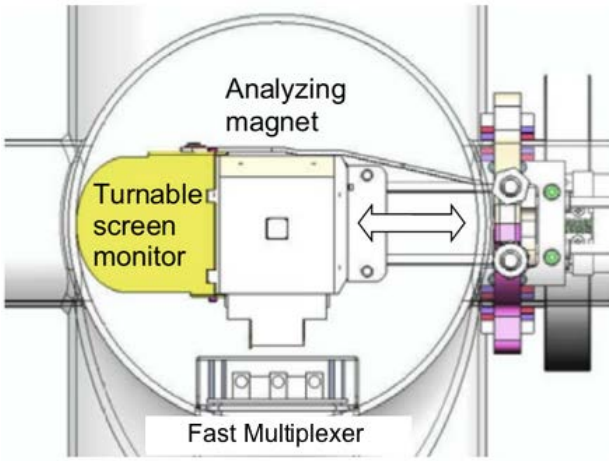

Figure 7: Front view of the compact analyzing magnet.

TEST RESULTS

Beam extraction tests with prototype of the analysis system were carried out. The train of the multiplexed analog signals from the collector electrodes are digitized by a PC based oscilloscope. This serial data has to be rearranged in two-dimensional way (see Fig. 8). It takes only tens of seconds from the start of measurement to displaying the result. There is a room for improvement of the latency to one second with an effort on software. As a result, the optimization of parameters of the ion source can be made quickly and the efficiency of optimization is greatly improved as compared with the previous method. Figure 8 shows an example of measurement results of extracted beam using the prototype. A higher current value is detected in a region where the display is close to yellow. A rapid time variation of ion species in a pulse is observed. Since the RF power may not enough and the parameters are not optimized yet in this example, the ion extraction starts after about 1 ms of the RF feeding. The signals around position 5 correspond to H_2^+ ions.

CONCLUSION

In order to analyze time variation of the ion species in a pulse quickly, we are developing a compact mass analyzer that has multiple collector electrodes to detect several ion species simultaneously. Prototype of the system has been developed and beam extraction tests are carried out. As a result, it is expected that optimization of parameters of the ion source can be performed efficiently.

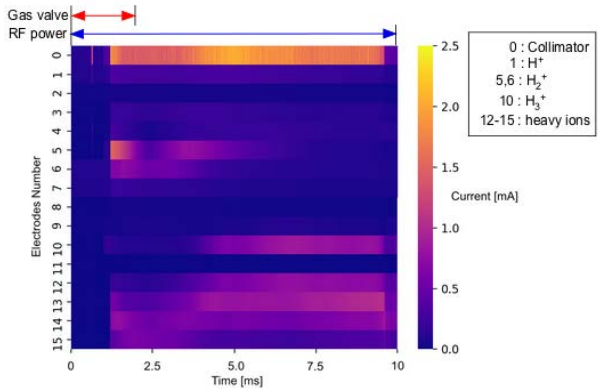

Figure 8: An example of measurement results. The vertical axis is the electrode number, 0 represents a collimator, 1 to 11 represent the main electrode, and 12 to 15 represent the sub electrode, respectively. The horizontal axis is time. RF power is fed from 0 to 10 ms and the gas valve is open from 0 to 2 ms. Bright color shows a strong signal.

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