The 6th Symp. on Accelerator Science and Technology, 1987, Tokyo, Japan (© Ionics, Tokyo, 1987)

DEVELOPMENTS AT THE RCNP AVF CYCLOTRON

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INTRODUCTION

The RCNP AVF cyclotron has been satisfactorily operated to pursue the nuclear research experiments and other related fields. During this decade since 1977, there are remarkable progrsses in its operation and many improvements of the components for the cyclotron; i) the beam current of polarized proton and deuteron has been increased so much, ii) proton and deuteron polarized in horizontal direction have been used for the experiments, iii) a pulsed arc power supply for PIG-type ion source could afford the highly charged light-heavy ions, iv) metal ions, such as lithium and calcium ions have been generated by using a sputtering method v) negative hydrogen beam was successfully extracted at the energy of 25 MeV.

Besides this progress, the beam quality was improved to respond for the strong demand from the researchers. These are i) stable beam current, ii) small emittance and/or good energy resolution, iii) highly charged and high current heavy ion beam, iv) high current polarized beam v) horizontally polarized beam with a constant polarization, vi) good time structure in microscopic beam bunch.

In these works, there are many findings among the accelerator performance affecting the beam qualities. We report in this paper, firstly the operation status of the cyclotron and secondary, several examples of the relation between cyclotron components and the beam quality.

PRESENT STATUS

The RCNP cyclotron is usually operated weekly starting at 21:00 on Monday and ending at 9:00 on Sunday. Operation statistics are shown in Fig. 1.

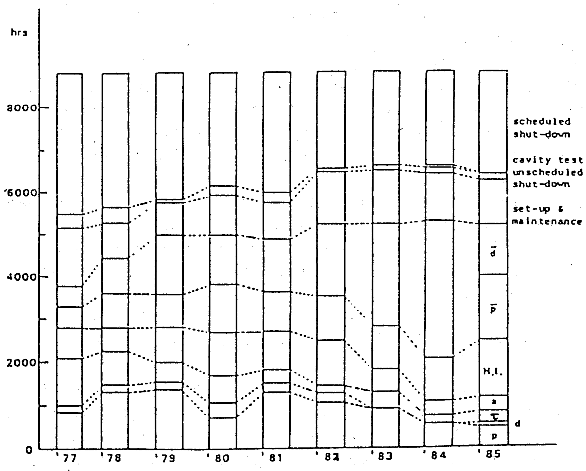

Fig. 1. Operation statistics from 1977 to 1986.

In recent years the beam time for polarized particles exceeded 50% of all the beam times. In order to meet the request from many groups of researchers, the accelerated particles, their energies and the beam courses were changed more than hundred times as shown in Table 1.

Table 1

	particle	energy	beam course
1979	110	140	88
1980	96	116	88
1981	103	124	88
1982	95	137	87
1983	97	136	102
1984	85	123	120
1985	100	127	84

MAIN MAGNET

The stability and reproducibility of the magnetic field of the main magnet are essential to keep the good beam quality and the beam current stability. Therefore, the current stability for the power supply was designed to be less than 1×10^{-5}/8h. Even so, it was occasionally found that the beam intensity at the Faraday cup of the particle spectrograph (RAIDEN) varied regularly in a period of a few minutes, whereas the fluctuation of the voltmeter for the main coil current was a few digit in 10^{-5} and the extracted current was very stable (at the end of 1978). After some investigation, it was found that these fluctuations were caused by a small change of the main coil current due to the failure of a temperature control unit for a reference voltage. At that time, we observed its change about several degrees, while an allowable difference is ±0.1°C. Consequently, the main coil current should be stabilized less than $\pm1.0\times10^{-5}$ at all times. To maintain this stability, there are many investigations in the power unit (mainly consisted of the motor generator and series transistors). Besides the example discussed above, there sometimes happened poor regulation due to a few reason; i) the replacement of the carbon brushes at the commutator ii) the deterioration of the zenor diode (the reference voltage) itself or for its power supply. At every shut down in July or August, the long term stability has been checked regularly. Their results show nearly 1×10^{-5}/day, as shown in Fig. 2.

Simultaneously, we observed quite interesting phenomena as in the following; i) the humidity around the motor generator system (set at the forced air controlled area) gives a worse effect to the current stability with a slow time constant, ii) after the replacement of the carbon brushes at the DC generator, and re-polishing their surface, there happens frequently spike noise over 5×10^{-5} (V_{p-p}), iii) at the initial setting or changing the current, the settling time was heavily affected by the cooling efficiency for the series transistors. At the poor cooling, the settling time is more than two hours, while the value reduces to less than half an hour at the better cooling.

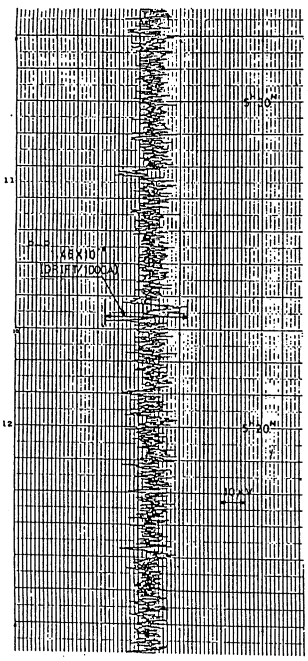

Fig. 2. Current stability of the main magnet power supply.

ACCELERATING VOLTAGE

During the all experiments, we can measure the difference between the rectified dee voltage and the reference voltage as shown in Fig. 3. By these measurements, it is noted that the stability of the dee voltage maintains nearly ~10^{-4}/ day, while this value comes 5~10 times larger at the heavy arc condition of the PIG-ion source or at the high frequency region over 18 MHz.

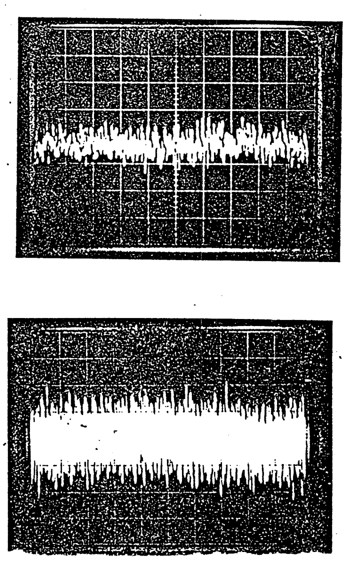

Fig. 3. The difference between the rectified dee voltage and its reference.

Recently horizontal polarized beam makes it clear that the dee voltage are closely related to the polarization of the extracted beam as shown in Fig. 4. The long term stability of the dee voltage can be estimated from the measurment of the horizontal polarization. However, as that value includes the total variations due to the dee voltage, magnetic field of the main magnet, ion source performance, total stability in terms of the dee voltage change is about 1×10^{-3}/33 hours.

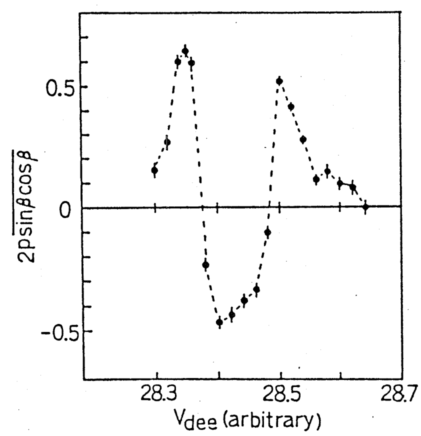

Fig. 4. Horizontal polarization as a function of dee voltage.

TRIM COIL

The beam behaviour of the microscopic time structure is the indispensable for a time of flight measurement.

The finer adjustment of the trim coil current and narrower width of the phase slit are the useful method to get the such smallest and stable time width of the beam, because the phase slit positioning and the trim coil current shifting are helpful to reduce the phase acceptance of the beam acceleration into a very limited rf phase. In this way, a beam pulse width as narrow as 0.5 ns was obtained.

Moreover, for moderate energy resolution and high transport efficiency, this method is effective though it is not so good resolution as by a small exist slit of the ion source.

For above two applications, the higher stability of the trim coil current is helpful to ensure these beam qualities. Typically the current stability is kept less than 1×10^{-4}/8hrs using the d.c. current transformer.

Recently, for atomic physics application, the best energy resolution, ΔE=3keV FWHM was obtained for 70 MeV ^{3}He beam, in spite of the worse beam transport efficiency by applying the 0.5 mm width object slit for a analyzer magnet.

POSITIONING OF THE ION SOURCE AND THE PULLER

The ion source and puller position is essential for the acceleration at the central region because the radial oscillation of the beam is excited by a careless setting of these positions. However, in the heavy ion acceleration, there happens wrong positioning by operators due to the entangling from the various low charge state ions in this region. In fact, for the third harmonic or fifth harmonic acceleration, these positioning is quite important for the extraction efficiency; it varies from nearly 0 to 30% by changing the radial position of the ion source and dee voltage.

For setting the acceleration condition in the central region, the visual display of the ion source and puller position are very useful to the operators. By employing the personal computer, initial region can be seen at the console with nearly 1mm accuracy.

TEMPERATURE CONTROL

Cooling water temperature or room temperature should be controlled to obtain better performance of the accelerator components. It is rearly true that it indirectly affect the all performances of the components; for example cyclotron vacuum, magnetic field stabilities, beam intensity, polarization, fine resolution of the beam, vacuum tube efficiency etc. We present two examples as follows; the 1st one is the diurnal variations of the vacuum at the main chamber, the second is the regular change of the polarization with the room temperature.

In order to reduce the worse effect, the cooling water for the analyzer magnet and the spectrograph (RAIDEN) has been stabilized in temperature by diaphragm valves with a electric and pneumatic servo system. In spite of this, there have been observed 50~60 ppm drifts of the magnetic field due to a large change in ambient temperature of the magnet and sometimes, in cooling water.

To compensate this variation the feed back system has been built by detecting the NMR signal. This enables us to improve the field stability up to $(4\text{-}6)\times10^{-6}$/6days as shown in Fig. 5.

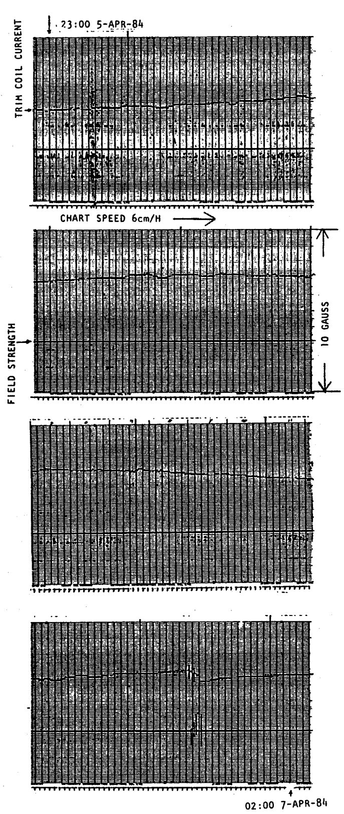

Fig. 5. Magnetic field of the analyzer magnet during days.

CONCLUSION

This stable and reliable machine performance makes it possible to set the machine parameter systematically. This is quite essential for the computer control of the accelerator, Moreover, these performances of all accelerator components can afford the stable and quite qualified beam more than one week.

REFERENCE

1) T. Itahashi, T. Fukuda, T. Shimoda, Y. Fujita, T. Yamagata and Y. Nagamine, Proc. 11th International Conference on Cyclotrons and their Applications, Tokyo, Japan (1986) pp. 664-666.