Time-Sharing-Acceleration in the HIMAC Injector

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Abstract

A Time-Sharing-Acceleration (TSA) system[1] has been developed in order to simultaneously supply different heavy-ion species from three ion sources to three courses: two synchrotron rings and the medium-energy experiment course. Two ion sources, 10GHz ECR and PIG, have already been in operation. A third ion source, 18GHz ECR, was installed in March, 1996, to produce highly-charged heavy ions. The replacement of the existing DC-magnets by pulsed magnets is almost completed. The control system of the whole injector system has been improved for TSA operation. The test operation began in March, 1997, and a problem was found when beams with very different q/A values are accelerated. This paper describes some developments concerning TSA operation, and the problem.

1. Introduction

HIMAC is being operated twenty-four hours per day from Monday to Saturday. The daytime is devoted to clinical trials of cancer treatment, while the nights and weekends are used for experimental studies of basic research. Figure 1 shows the operation time of the HIMAC injector. Since clinical trials employ C beams, C beams occupy a large part of the operation time. A variety of ions including Ar, Ne, Si, He, and H_2 are also used in the experiments. Since the beam time during weekdays is used for clinical trials, the available beam time for the experiments is limited.

At present, a fixed ion species from one ion source can be supplied to three user groups: the two synchrotrons and the medium-energy experiment course. If the ion species can be changed per pulse, three users can share the beam time, and the available beam time for experiments increases

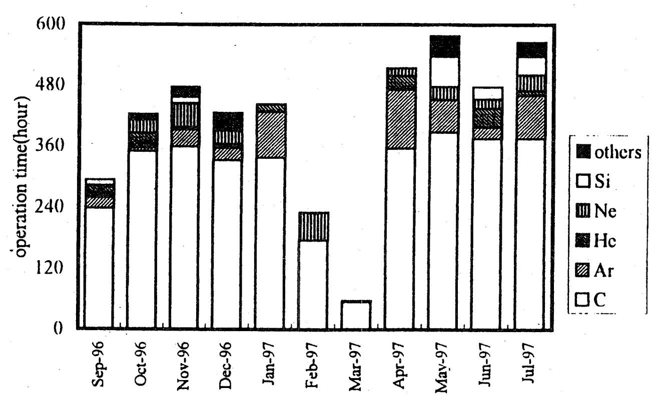

Fig. 1 Operation time of HIMAC injector.

significantly. In order to realize this operation mode, we have developed a time-sharing-acceleration (TSA) system at the HIMAC injector. In the TSA mode, it is necessary to accelerate three kinds of beams with different q/A values. The modification to TSA includes a replacement of all DC-magnets, power supplies and control systems. The test operation began in March, 1997. The modification and testing of the new system is, however, expected to span a few years, because the long halts of operation in the medical accelerator is not justifiable.

2. HIMAC injector

Figure 2 shows a schematic drawing of the HIMAC injector. Two ion sources have been in operation: 10GHz ECR, PIG at the HIMAC injector. A new ion source, the 18GHz ECR, was installed as a third one. The heavy

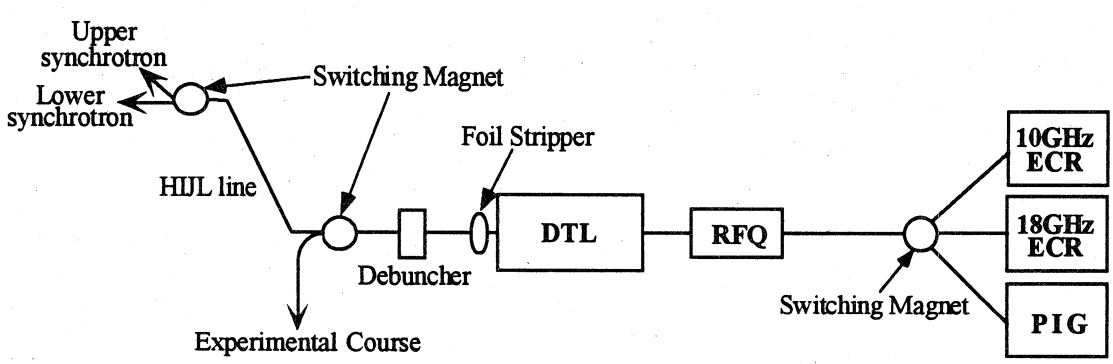

Fig. 2 Schematic drawing of the HIMAC injector, including the HIJL line.

ions from ion sources are accelerated from 8keV/u to an energy of 6MeV/u by two types of linacs, and are supplied to three courses: two independent synchrotron rings and the medium-energy experiment course. The HIMAC injector consists of the RFQ linac, three Alvarez-type linac tanks (DTL), of which the RF frequency is a 100MHz. The debuncher (maximum RF power of 30kW) is installed downstream DTL, in order to reduce the momentum spread of the accelerated beams to $\pm 0.1\%$. Figure 3 shows a block diagram of the RF system. Each RF source contains RF control circuits (AGC, APC and AFC), a transistor amplifier and 1-3 stages of amplifiers using tetrode tubes. The maximum RF repetition rate is 3Hz and the maximum RF pulse width is 1.2msec. The AGC (automatic gain controller) controls each RF amplitude and the APC (automatic phase controller) substantially controls the phase between the cavities. The AFC (automatic frequency controller) stabilizes the resonant frequency to 100MHz by adjusting the position of the cylindrical auto-tuners in the cavity with the phase error signal between the input and pick-up signals of the linac tank.

The maximum RF powers are 300kW for RFQ, and 1.4MW for DTL; these linacs were designed to accelerate heavy ions with q/A values of from 1/2 to 1/7[2]. The RF powers, which are equivalent to those q/A values, are 20 – 250 kW in RFQ and 90 – 1100 kW in DTL. When high RF power (>550 kW in DTL and >120 kW in RFQ) is required, it is necessary to gradually increase the RF power prior to operation and to carry out sufficient degassing of the resonators, in order to suppress electric discharging during operation. So far, the RF power corresponding to q/A values from 1/2 to 1/6 has been stably supplied, and beams (H_2^+, $^{12}C^{2+}$) equivalent for these q/A values have been accelerated.

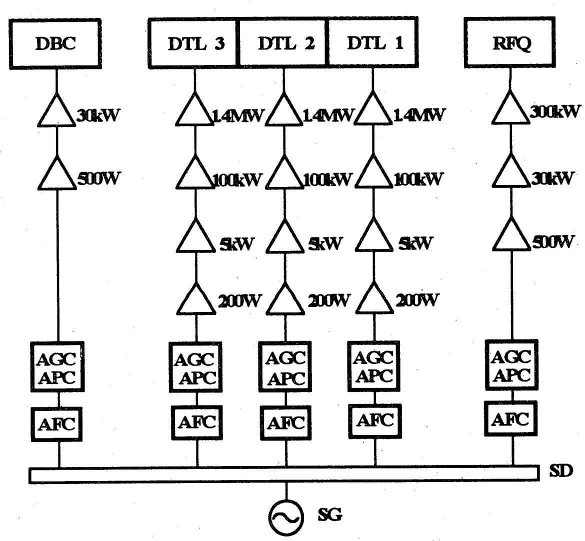

Fig. 3 Block diagram of RF system.

3. Modifications for the TSA operation

Figure 4 shows an example of a time chart of the injector operation during TSA. Three ion sources are triggered in order. The RF powers and Q-magnets are excited according to the q/A values of the ion species, and three beams are distributed to the three courses.

In order to realize TSA operation, modifications were carried out as described in the following subsection.

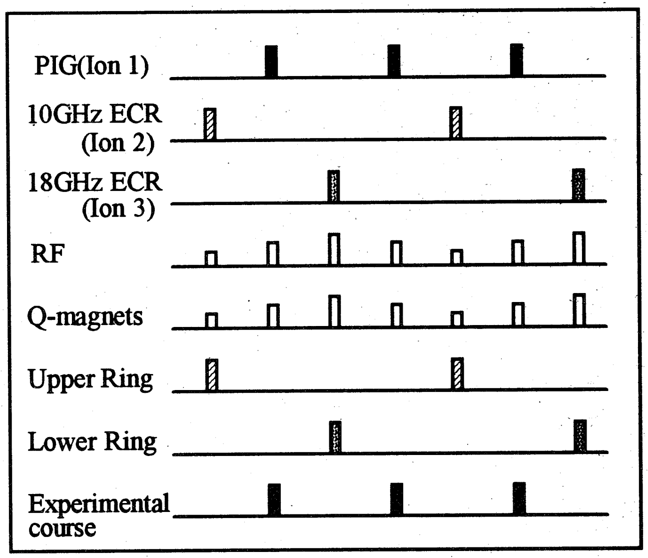

Fig. 4 Time chart in TSA operation. RF and Q-magnets show the excitation level, and the others show the beams.

3.1 The 18GHz ECR ion source

The HIMAC injector was originally equipped with two ion sources, 10GHz ECR and PIG. A new 18GHz ECR ion source[3] was installed in March, 1996, to produce mainly highly-charged ions, such as Fe^{9+}, Kr^{13+} and Mg^{5+}.

3.2 Magnets in the transport line

All of the existing DC-magnets have been replaced by pulsed-ones which can work at a repetition rate of 3Hz. Q-magnets and power supplies in the transport line, except for the HIJL line (Fig.2), were replaced in March, 1997. The switching magnet to switch the ion beams from each ion source to the RFQ linac was also replaced by a new one. Figure 5 shows the switching characteristics of this magnet. The rise and fall time was chosen to be 45ms in order to cope with the 3Hz repetition. The required time for the flat top is 700 μ s to supply stable beams to the linacs, while the obtained time, 25ms, is long enough for this requirement. This new magnet can quickly change both the excitation level and the polarity. Two other switching magnets, to distribute the beam to the two synchrotrons and the medium-energy experimental course, were originally pulsed-ones.

The magnets of the HIJL line were replaced by August, 1997.

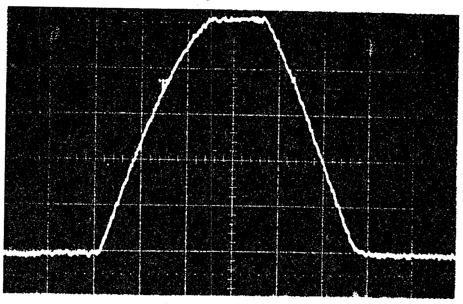

Fig. 5 Switching characteristics of the pulsed switching magnet for ion sources. T_{rise} and T_{fall} are 45ms.

3.3 Modification of the control system and the operation console

All of the devices are controlled by UDCs (Universal Device Controller). UDCs were modified so as to accept three trigger pulses corresponding to the three ion sources. A parameter selected by the trigger pulse is set from pulse-to-pulse basis.

The software of the control system was also modified to prepare three parameter sets corresponding to the three ion sources. Each set defines a pair of ion source and the beam course used, and includes lists of the device parameters.

We have only one operation console for tuning the whole injector. The policy of the man-machine interface is maintained to be the same as before in order to make the switchover to TSA operation easy. From this point of view, a common interface to other sub systems (synchrotron and beam delivery) is also maintained. There are three processes, which correspond to the three different ion sources, in the new software. The operation console is, thus, assigned to one of the parameter sets by a hardware switch. An operator changes the assignment and sets the parameters successively.

3.4 Modification of the beam monitors

The beam monitors, such as the Faraday cups, slits, profile monitors and emittance monitors, were also modified so as to distinguish the beam from different ion sources. Unfortunately, these devices are beam-destructive, and may not be suitable for beam conditioning while the other beams are in use. Electrostatic pick-up monitors were, thus, developed. Using a couple of these monitors, a measurement of the beam energy (velocity) by a TOF method[4] will also be possible in the future.

3.5 Modification of the linacs

The RF system was originally pulse-operated, though with one trigger. The controllers (AGCs and APCs) were thus easily modified so as to work with three kinds of triggers corresponding to the three ion sources. The modification was carried out in March, 1997.

Quadrupole magnets inside the drift tubes are also pulse-operated. It was thus easy to modify the control system of the magnets, working with three kinds of triggers.

4. Beam test and a problem related to TSA operation

We have tested TSA operation, in spite of the limited time, since April, 1997. Up to now, beam tests of the TSA were successfully carried out using two kinds of beams for two cases: 1) He^{+} and C^{4+}, 2) C^{2+} and Si^{5+}.

A problem concerning the auto-tuners of AFC was recognized in the beam tests. The optimum tuner position depends on the RF power levels. When heavy ions with very different q/A values are accelerated in TSA, the optimum tuner position per pulse should be different. In order to realize the optimum-resonance condition for all triggers, it is necessary to move the auto-tuners by about 3mm between the beam pulses. However, the present system allows only 0.67mm movements of the tuners at the RFQ and the debuncher, and 0.83mm at the DTL. Furthermore, the rapid and frequent movements would put a limit on the life of the tuner, even if the system was modified to allow such rapid and large movements. As a solution, the trigger was selected in such way that the position of the auto-tuner is controlled by one of the trigger pulses, i.e. one of the beams. Usually the beam having an intermediate value among the three beams is chosen. This scheme allows us to supply sufficient power at all of the triggers, although the resonant condition is not always perfect.

5. Conclusion

The TSA system, which allows simultaneous acceleration of three kinds of ions, was designed and is under construction for the HIMAC injector. A test operation of TSA has been carried out using different ion species with similar q/A values. More detailed tests will be continued until April, 1998.

Acknowledgement

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