Progress in HIMAC Accelerator Operation

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Abstract

HIMAC accelerator has been in operation for four years, without major unscheduled down time. Clinical trial of cancer radiotherapy, as well as physics and biology experiments are served well by HIMAC beams. Operational experience of the accelerator complex is reported from the viewpoint of operations crew and staff in an application oriented machine. Efforts for highly reliable and stable beam supply are described on both operation and maintenance aspects. Approaches to save time and manpower without reducing the reliability of beam are also reported.

1.Introduction

Unlike accelerators in physics research, application oriented machine is required to be operated and maintained in a fully functional condition without help from a large number of accelerator physicists. Furthermore, administrative regulation on manpower directs new way of running a big accelerator complex. Since the machine was built by four independent manufacturers, no single firm of each sub system of HIMAC can really operate the system as a whole.

AEC was founded by a joint effort of companies including Mitsubishi Electric Corp., Toshiba Corp., Hitachi Ltd., and Sumitomo Heavy Industries Ltd., in November 1992. It then started to function as a company to provide onsite operation and maintenance service of the HIMAC facility, as well as support for R&D work relevant to HIMAC accelerator. The chronological record of the HIMAC commissioning and operations shows AEC's commitment. In January 1993, AEC began to operate ion sources and linacs, which accelerated the first beam in March '93. The installation of main synchrotron ring and transport lines was completed in summer '93, when the maintenance of HIMAC building plant (power lines, air conditioning, water and other utilities) were assigned to AEC. Figure 1 shows plan view of B2F where injector and one of the main rings are installed. Then in September, as manufacturer tuning by parts was completed, AEC was entrusted to operate and maintain entire HIMAC facility under supervision of NIRS Accelerator Operations Section. Beam commissioning commenced then in November and we obtained the first beam accelerated and extracted from synchrotrons in December. Clinical trial started in June 1994, and continuous operation from Monday to Saturday was introduced since October '94, during this period AEC expanded its charge to include support to physics experiment and treatment planning. Several R&D work on power supplies, beam monitors, radio frequency acceleration, vacuum system and other relevant fields have been carried out under suggestion of and in collaboration with NIRS researchers. From FY 96, the preventive semi-annual maintenance of HIMAC was also put into AEC's responsibility. Number of AEC people who worked at HIMAC accelerator operation are nearly 40. This number includes the above-mentioned activities of AEC from daily operations to long term maintenance and R&D work for HIMAC performance improvement.

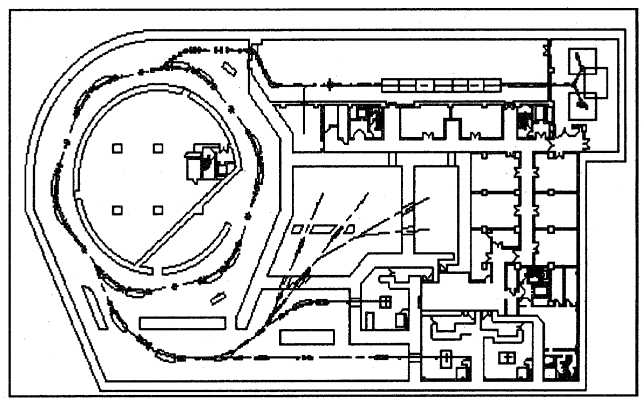

Fig. 1 Layout of the HIMAC B2F

2. The operation of the HIMAC

As medically dedicated machine, HIMAC operation is dictated by therapeutical needs. [1] Present common practice of particle therapy consists of about 10-20 times irradiation of the target cancer. Each fraction of irradiation takes typically a few minutes but usually it is carried out once a day per patient. It means that a treatment is a matter of weeks, if not months, for individual patient. Implication is that acceleration for a medical treatment must be able to deliver beam stably during the extended period of 6 weeks per patient. Further, as the number of patients grows up, one patient will start treatment right after another patient's treatment. Therefore the beam must be available to irradiate patients, for an extended period of more than a couple of months. The beam schedule is thus to assure beam time for therapeutic use as long period as possible. At present, we shut down the machine in August and March for semi-annual 5-week-long maintenance. Break at the end of calender year is limited to about one week. It left us about 39 weeks of therapy beam supply, after taking one week of re-confirming period for beam characteristics following each shutdown. To operate the machine as much stable, we devote every other Monday to work on maintenance.

Weekly operation pattern is shown in Fig. 2. Therapy beam time is from Tuesday to Friday, 9 a.m. to 7 p.m., daily. During this time, carbon beam with intensity of $3x10^8$ particle per second must be supplied constantly. Since the therapy utilizes different value of beam energy to conform various tumor site in patient, we change the energy according to treatment schedule. In the horizontal beam 290 MeV/u and 400 MeV/u, and 290 MeV/u and 350 MeV/u for vertical one. It is typically during lunch break for medical staff, and about 30~40 minutes time is necessary to adjust and confirm the beam. We save the parameters such as power supply current, static deflector voltage, rf phases, event timing, and so on, in a 'file' and try to operate the machine simply reloading and setting the filed value. The system proves itself by reproducing beam through the filed parameter operation and residual amount of tuning is made minimal. During the beam-field confirmation and treatment run, beam position and intensity are monitored continuously by a multi-wire chamber at the downstream of each beam course. Wave form setting for respiration-gated irradiation is also done by operator for minimizing the time for treatment.

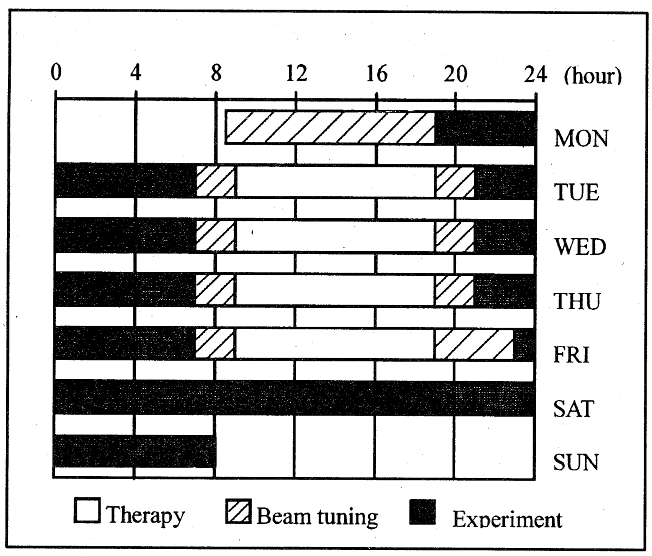

Fig. 2 Week operation schedule

Night shift is provided for biology and physics experiment after therapy. Since these experiments need different beam energy and or intensity level. It is necessary to change energy and other parameters of the beam at the beginning of the shift. It is also necessary to return to medical beam in the morning. As for weekends, various ion species other than carbon are accelerated for physics and biology experiments. They include Si, Ar, Ne, He, and others, which are shown in Fig. 3. Tuning for different ion takes about two hours, mostly at extraction and transport from ion source to RFQ linac, even after establishing a 'file'd parameter at the preceding beam time. As for synchrotron ring, beam acceleration for Q/A = 1/2, parameters can be commonly used and reproducible. In Table 1, energy and intensity values of lower ring operation are listed.

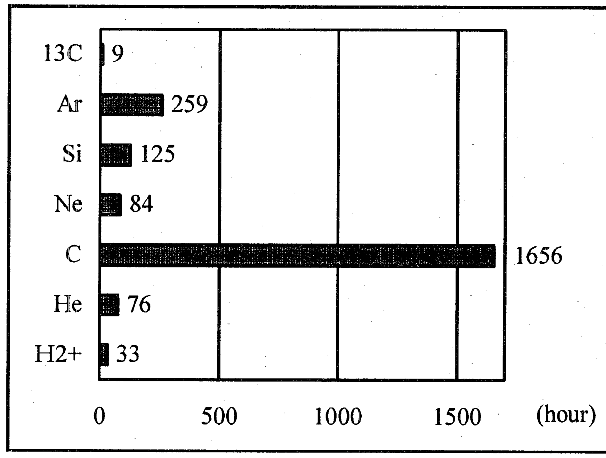

Fig.3 Accelerated ion (April, 1 to August, 2, 1997)

Energy [MeV/u]	Ion	Ring DCCT [pps]	HEBT [pps]
6	He,C,Ne,Si	He 1.0E+10	
75	Ar,(Si^{+13})	Ar 2.6E+7	2.3E+6
100	He,C,Ne,Si	C 1.0E+9	
	^{13}C	1.9E+9	6.7E+8
	^{22}Ne	8.5E+8	
135	He,C,Ne,Si	No data	
150	He,C,Ne,Si,(Ar)	C 1.1E+9	6.7E+8
160	H_2^+	2.0E+10	1.4E+10
180	He,C,Ne,Si	C 2.0E+9	1.5E+8
230	He,C,Ne,Si	He 8.0E+9	6.0E+9
	H_2^+	1.4E+10	H 1.3E+10
290	C,Ne,Si,(Ar)	C 2.0E+9	1.9E+9
350	C,Ne,Si	C 9.3E+8	7.5E+9
390	Ar^{+17}	1.4E+8	
400	C,Ne,Si	C 2.0E+9	1.9E+9
401.78	Ar^{+17}	1.4E+8	
430	C,Ne,Si	C 1.5E+9	1.0E+9
600	Ne,Si	Ne 8.5E+8	7.7E+8
650	Ar	1.4E+8	4.1E+7
800	Si	4.5E+8	1.8E+8

Table 1. Energy and intensity values of extracted beams (Lower ring)

3.Daily Operation and improvements

HIMAC accelerator is now operated by operator crew of 3, who are looking at Injector (ion-source and linacs), Synchrotron (both rings), and Transport (including interfacing with treatment/experiment). This number is a reduction from initial 7 people crew, and is a result of intentional effort on making common knowledge and skill of operation and maintenance. However, additional support is required for operation of other-than-carbon ion, presently.

Further effort is necessary to proceed more in decreasing operators.

In an effort to reduce the time necessary for energy change, the effect of "initialization" procedure was checked and it was found that the magnet at extracted beam transport line needs to be "initialized" to nullify the histeresis effect, while the effect in the ring magnet is not recognizable. With this finding, energy change procedure in synchrotron is modified and beam alignment at the connection from the ring to high energy beam transport line is simplified, gaining typically 5~10 minutes in the process. Development of automatic tuning for the transport line is under progress and will aid tuning operation of unexperienced operator.

It is also important to meet the request from experiment user on beam shape, intensity and stability, etc., as much as possible. Request for a small beam spot can be met by adjusting HEBT Quadruple magnet strength. Request for more beams at high energy is not always fulfilled. One of the reasons is a lack of tuning time because we cannot accelerate carbon ion more than 430MeV/u due to radiation safety regulation. We set aside every other Monday for beam acceleration tuning of those new ion/energy, but it was not enough to obtain the best tuned and reproducible parameters.

Another problem is to stabilize the beam at 10^2~10^3ppp level, which is very sensitive to beam path at beam-attenuating point, and condition of stabilization often differs from the previous one. We need more careful study on beam transport and acceleration in this problem.

4. Trouble and Maintenance

Various kinds of trouble were experienced during the last three years. Major troubles that delayed beam supply for more than one-hour occurred about two-three times a year. In '95, a magnet-coil burn out due to improper regulation of coil water circuit, water leak from RF high power amplifier system water-cooling. In '96, water loss because of over-fastened and broken packing in the mother line of cooling water system, DTL RF high power trouble due to power tube and/or high-power amplifier failure. In '97, power tube filament broke. So far, there were only two days when machine trouble caused cancel or postponement of entire day of treatment. We need to keep and improve the down time rate as low as possible. In this line, preventive maintenance work is very important. As can be seen from the above incidences, water leak or loss is one of the major sources of trouble. Checking and adjusting water flow at each device is among the menu of Bi-weekly maintenance, as well as repair/calibration of individual flow meter.

Maintenance work has been carried out by subsystem (Injector, Synchrotron, Transport) or "group" basis because of different starting point in manufacturing and commissioning. However, since the component technology is common, we pursue re-grouping of the work in terms of field, such as, power supply, beam monitor, vacuum system, control computer etc. Also, development work is organized such that members from all subsystem group is engaged to new 18 GHz ion source development. Table 2 shows the technical items of HIMAC and number of assigned engineers from AEC.

Technical items		Number of engineers
Ion Source	PIG	2
	ECR(10&18GHz)	3+3
RF System	Injector	2
	Synchrotron	3
Vacuum system		4
Magnets and power supply		4
Beam monitors		4
Control systems incl. timing and interlocks		5
Computers and network system		4
High voltage devices		2
Cooling system		2

Table 2. HIMAC operations activity in technical items

5. Outlook

In order to combine and reduce the load of operator, more utilization of supervisor system is now discussed together with an introduction of so-called Time-Sharing Acceleration. Important pre-requisite is that system can be operated in the same operation sequence and operators are capable of at least daily operation of entire system.

Another aspect to reduce load of the operator is to transfer some of the manipulation to user-experimenter: For example open/close of beam shutter and mesh attenuator in the injection beam line can be done by user. (Interlock system must be maintained as before.)

6. Acknowledgement

We would like to thank researchers at the Accelerator Physics and Engineering Division of NIRS headed by Dr. K. Kawachi for great warmhearted guidance of HIMAC operation.

7. Reference

[1.] E.Takada et al. "Present Status of NIRS-HIMAC", in these proceedings.