Present Status of NIRS Medical Accelerator – HIMAC

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Abstract

The NIRS heavy–ion medical accelerator facility, HIMAC, is coming to the final construction stage. All elements of the accelerator system were delivered. Successful beam acceleration test of the injector linac system and thus its commissioning is one of the most important progress in the last one and a half year. The elements of synchrotrons, high–energy beam transport lines, and irradiation equipments are accurately aligned and are under operation tests at the institute extensively toward completion by the end of this year, 1993.

This paper briefly describes a present status of the HIMAC facility at the middle of the year. The feature of field control of lattice magnets of the synchrotrons is discussed as another sample of the progress since the last symposium.

Introduction

Heavy–Ion Medical Accelerator in Chiba (HIMAC) at National Institute of Radiological Sciences (NIRS) is dedicated to heavy–ion cancer therapy and is the first heavy–ion medical accelerator facility in the world. The accelerator is capable of variable particle, variable energy, and variable intensity to satisfy medical requirement such as a long residual range of 30 cm in human bodies and a high dose rate of 5 G/min at therapy rooms. In addition, stable and reproducible operation is strongly required for the medical use.

The HIMAC facility is divided into four systems. Main accelerator is two identical synchrotron rings installed at upper and lower underground floors of the building. Injector accelerator is a cascade of an RFQ linac and an Alvarez linac preceded by two kinds of ion sources, a PIG source and an ECR source. High–energy beam transport system consists of vertical and horizontal beam lines which deliver the beam from the upper and lower rings to three treatment rooms and experimental irradiation rooms. One of three therapy rooms is equipped with simultaneous vertical and horizontal beam irradiation port, while the others are equipped with vertical only and horizontal only, respectively.

Since HIMAC had been approved by the Government in 1987 as a seven year project, contracts with companies for fabrication and delivery of accelerator elements of each system have been made from 1987 to 1991. Construction works for the building including associated facility such as power substation and air–conditioning system have been contracted from 1987 to 1993 through the regional office of the Construction Ministry and is to be completed in the middle of 1993. While Mitsubishi Electric Corp. became the main contractor of the accelerator construction, the arrangement is such that Sumitomo Heavy Industries, Ltd. took charge for the injector linac system, and that Hitachi Ltd. and Toshiba Corp. shared the responsibility for the synchrotron system. Mitsubishi Electric Corp. herself was assigned for the high–energy beam transport system, the irradiation system, and water–cooling system for the accelerators. Each company further called various sub-contractors to meet the state–of–the art specification of many devices and techniques. In addition, a new company, Accelerator Engineering Corp., has joined in the last year for operation and maintenance of the HIMAC facility. The final contract for installation, operation tests at the institute, and beam tuning is made in 1992 and 1993 aiming at completion of the HIMAC facility in the 1993 fiscal year.

The delivery of the injector system had started in the early part of 1992 and the other system in the middle of the same year, respectively.

Present status of the HIMAC facility

In Fig. 1(a) to 1(i), recent photographs of significant elements of each system are collected together with a schematic bird's eye view of the whole facility.

As of July, 1993, all construction works of the building and the accelerators are nearing to the final stage. The building is being reviewed for inspection and a final civil engineering work is underway as seen from Fig. 1(i).

Beam acceleration test of the injector linac system was carried out this spring with satisfactory results[1], which is discussed later. Concerning the other systems, elements are being installed and are under operation tests without beam.

In the case of the synchrotrons, the accurate alignment[2] of elements such as magnets, beam monitors, and electrostatic inflector and deflectors has been completed and vacuum ducts for them have been assembled as shown in Fig. 1(e). At present, all vacuum components of the lower ring are being baked out at 200℃ for high vacuum[3]. On the other hand, preliminary tests on power supplies for ring dipole magnets and quadrupole magnets have started although a bridging bypass resistor for a magnet coil[4] will be equipped later very soon. In addition, on–site tests of a computer control system[5] are being made. At the end of this year, the beam from the injector linac will be transferred to the synchrotrons.

In the case of the high–energy beam transport system, it was already at the checking stage of major magnet power supplies for the system in early 1992. Those power supplies showed satisfactory stability for 8 hour run at a manufacturer. Vacuum system was also extensively checked and sequence control of turbo molecular pump sets was adjusted. Most of the beam line elements including profile monitors were delivered in the last year and were aligned subsequently. Alignement of the vertical beam lines has been completed recently.

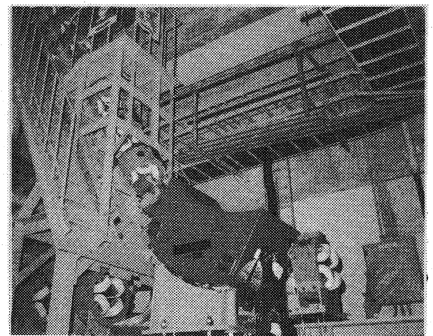
For the treatment and irradiation system, the wobbler magnets and their power supplies were tested and installed. Several devices for beam collimation and range modulation such as ridge filters, range shifters, block collimators, and multi–leaf collimators were also delivered and aligned.

The global interlock system and supervisory computer have been installed and connection to each subsystem is being examined.

The building has been constructed from year to year for the reason of the budget based on the scheduled contracts as described above. Movement of the building[2], however, was unavoidable during a period for initial installation and accurate alignment because there was no enough time between the construction of the building and the installation of the accelerator elements. Main component seems to be such uniform movement as rolling and pitching of the building as a whole. Detectable movement seems to occur within one month or so. The accurate alignment of the accelerator elements is being extensively made in as short period as possible in order to overcome this problem.

In the following, two topics will be highlighted to show the recent result of the HIMAC accelerators.

Fig. 1 Schematic bird's eye view and recent photograghs of HIMAC facility
(a) Schematic bird's eye view
(b) Ion sources: ECR(front) & PIG(rear)
(c) Injector linac cascade: RFQ(front) & Alvarez(rear)
(d) Injection beam line: Switching mag. for both rings
(e) Lower synchrotron: BM+QM(front) & RF(rear)
(f) High-energy beam line: Horizontal beam line
(g) Irradiaiton device: Wobbler mag.
(h) Therapy room: Vertical line to be installed
(i) Building



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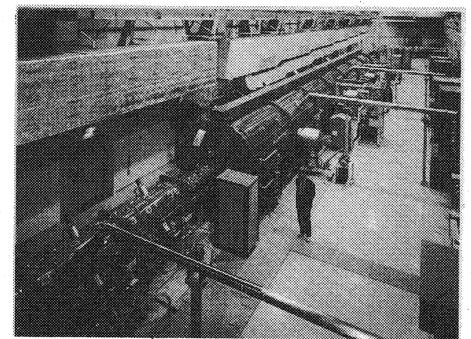

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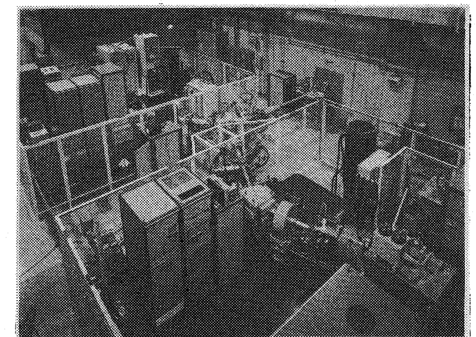

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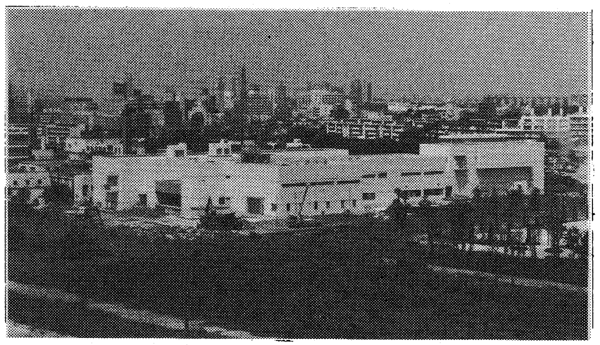
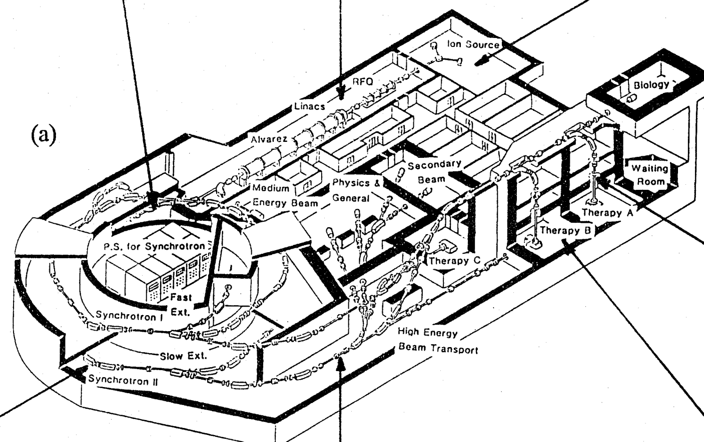


(i)



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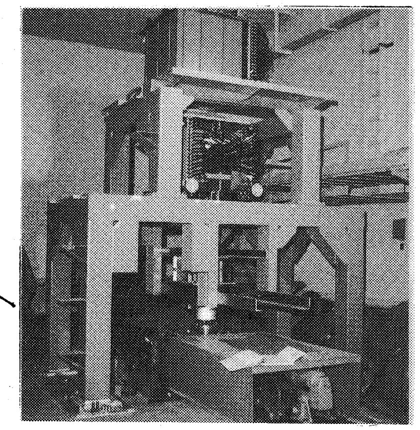
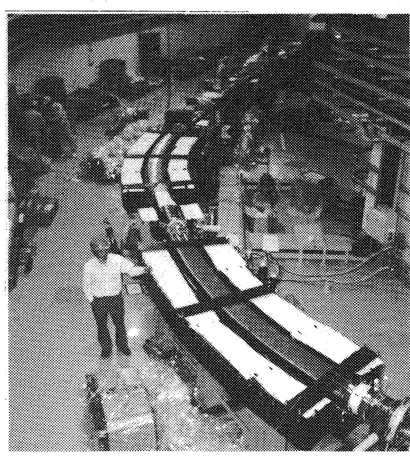


(g)



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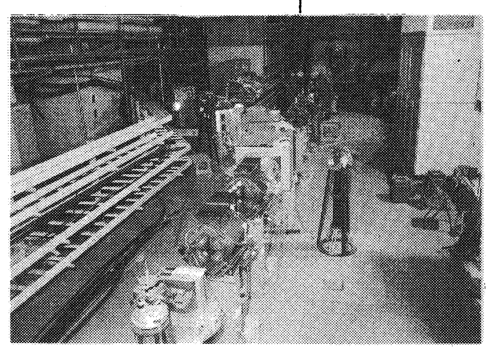

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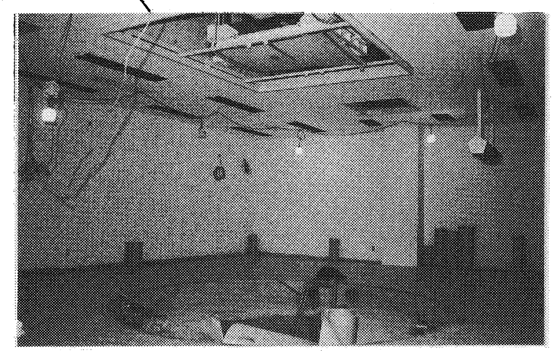

(h)

Commissioning of the injector linac system

The injector linacs had been once assembled accurately at the company and were powered successfully without beam acceleration. The linacs were then appropriately divided into several tanks for shipping, each of which was delivered to the institute. Because elements such as vanes of the RFQ linac and drift tubes of the Alvarez linac were kept at proper positions for shipping, main works after the delivery were careful joint between the tanks and accurate installation as a whole of the each linac. In addition, because a period for installation and alignment was rather short, the movement of the building, which is described above, did not affect on these works. Figures 1(b) and 1(c) show photographs of the ion sources and the cascade of the RFQ linac and the Alvarez linac, respectively, after completion of installation in February, 1993.

As soon as the electric power substation and the water-cooling system had become available, operation tests of the linacs have started. Multi-pactoring due to rf power excitation was easily overcome. Ion species for the first beam was chosen to be He^{1+} ions because of lower rf power level and enough intensity produced at the ion source in comparison to those of ions with a charge to mass ratio of 1/7. The acceleration tests have finished very soon because of no major trouble. Such performance of the beam acceleration for 6 MeV/u by the linac cascade as transmission efficiency of about 90 %, beam intensity of 800 eμA, and normalized emittance of 1 π•mm•mrad is proven to be almost same as design values. This success leads us the commissioning of the injector linac system very quickly.

Field control of synchrotron magnets

Field distribution of lattice dipole and quadrupole magnets had been extensively computed in 2-dimensional calculation during the design period. Cross section of the magnets are then manufactured on the basis of the computations. Performance of the magnets, however, is much affected by leakage field around pole ends along the beam direction. In order to realize the nice overall performance of magnets, we have attached adjustable and demountable end pieces for both dipoles and quadrupoles. In the case of the dipoles, the end pieces are adjusted in thickness to achieve the same product of field strength and effective length, BL, just on the beam axis for all dipoles of the ring. In the case of the quadrupoles, the end pieces are adjusted in shape to achieve the uniform radial and vertical distribution of a product of field gradient and effective field length, GL(x) and GL(y).

The product BL on the beam axis of the dipoles is once normalized at a field strength of 1 T experimentally by means of thickness adjustment of the end pieces in measuring a deviation of BL from the reference magnet. Measured data of deviation of BL at low and high field strength are then plotted in a two-dimensional figure: for example, a horizontal axis for deviation at the low field and a vertical axis for that at the high field. It is noticed from the figure that the deviations at low and high strengths have a correlation that the data for many magnets tend to fall on a straight line. It is considered from a natural extension of Ampere's law that a lower remanent field results in a higher permeability and vice versa due to the characteristics of ferromagnetic material of magnet core. This analysis has been very helpful to confirm a validity of the field measurement because erromeous data is away from the line largely.

In addition, the relation between the deviations at the low and high fields is applied to decrease a closed orbit distortion in wide dynamic range of the field strength on the basis of appropriate shuffling of the magnets, because the all magnets are normalized at 1 T in BL and deviations at low and high fileds have opposite values.

A new expression for fitting between a field strength and a coil current is proposed to be a sum of two inverse polynomials as a natural extension of Ampere's law, too. It is featured that most of all parameters in the expression correspond to physical quantity of the magnets such as a remanent field and a magnet gap. A preliminary fitting result based on the 4th order polynomials shows an agreement in the observed value of a remanent field and the design value of a magnet gap. Consequently, it is confirmed from the agreement that fabrication of the magnets and field measurement including measurement of coil excitation current are valid.

Radial and vertical distribution of GL(x) and GL(y) of the quadrupoles is adjusted extensively in a given boundary condition of the end pieces to achieve as uniformity independent of coil current as possible. In order to control the distribution easily, a nice method has been found[6]. The end pieces consist of stacked sheets and are finally glued for a solid block. The end pieces were originally shaped in a regular step with a given width of tread on the basis of an appropriate straight line. We have observed the effect of sheets of each step on distribution of the GL product to increase or decrease the sheets. Combining the effect of each step, we have achieved a nice distribution.

Summary

All elements for the HIMAC accelerators have been tested at the companies to confirm the performance before delivery to the institute. For examples, such measurement as field distribution and excitation curve have been made for magnets, operation tests for actual or dummy loads have been made for power supplies, and operation tests such as rf power excitation have been made for devices such as rf accelerating cavities. These measurements and tests have shown the performance that meets the specification. Special procedure such as field control of the dipoles and the quadrupoles has been newly developed during this period for measurements and tests.

Presently the HIMAC accelerator facility is coming to the final construction stage of the seven year project which had been approved in 1987. Commissioning of the injector linacs has been made recently. Elements of the other system were delivered, are being aligned accurately, and are under tests one after the others extensively to aim at beam transfer from the injector linac to the synchrotron in the later part of 1993.

Acknowledgement

There are so many works for the entire HIMAC facility. In particular, all elements should be manufactured precisely, aligned accurately, and tested carefully by very many persons in order to satisfy the specification. The authors are much indebted to them for efforts toward the completion in the 1993 fiscal year. Staffs of the institute, guest scientists, and engineers of many companies concerning the HIMAC project are greatly acknowledged.

References

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