DEVELOPMENT OF COMPACT PROTON ACCELERATOR FACILITY DEDICATED FOR CANCER THERAPY

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Abstract

Responding to the increasing needs for charged particle cancer therapy, a proton accelerator facility dedicated for cancer therapy has been developed. A combined function proton synchrotron with the maximum energy of 250 MeV has been designed with an untuned RF acceleration cavity powered with a solid state amplifier by a newly invented multifeed coupling. Enlargement of irradiation field by a scanning method has also been studied because of its higher beam utilization efficiency and possibility of precise dose distribution.

1 INTRODUCTION

Radiation therapy is considered as one of the most important items for cancer therapies because of its merits of preservation of shape and function of human body and rather mild load to the body of the patient. Charged particle therapy, especially, has recently become to be paid attention because it can localize the radiated dose to the tumor volume utilizing Bragg peak characteristics. In Japan, already several institutions have started construction of charged particle therapy facilities stimulated by the start of clinical trial using carbon beam at HIMAC in NIRS.

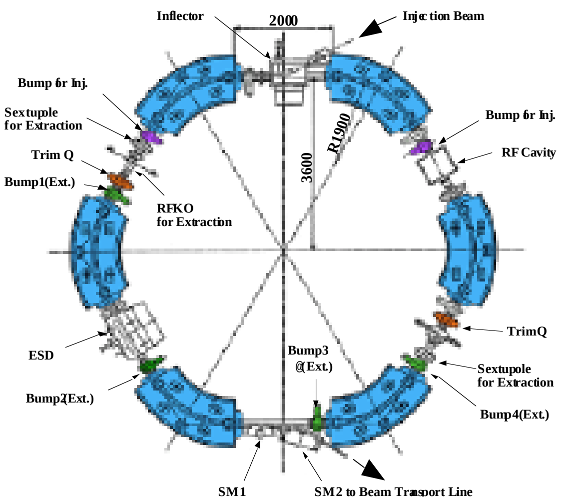

Fig.1 Combined function synchrotron dedicated for cancer therapy.

The number of patients, however, who can be treated by these facilities are rather limited and it is important to distribute a compact therapy facility in such a hospital as takes the role of the center of each prefecture. In order to establish a good reference design of a dedicated accelerator facility for proton therapy, we have developed a combined function proton synchrotron.[1] As the acceleration cavity, we have also developed an untuned RF cavity powered with a solid state amplifier by a multifeed coupling which feeds each ferrite separately through a loop coupling. Such developments have been performed emphasizing the points to reduce the construction cost and operation man-power.

The merit of the synchrotron exists in its energy variability. In order to fully utilize this merit, we are proposing 3-dimensional scanning method as the ideal goal. The beam spill of the slowly extracted beam, however, usually has time varying characteristics . This has been considered as the most fundamental neck for realization of scanning method at synchrotron facility[1]. A beam intensity monitor of a good frequency response has been developed for a speed control system of the scanning magnet to make enlarged irradiation field.

2 COMBINED FUNCTION SYNCHROTRON

One of the difficulties in controlling the synchrotron is synchronization of excitation currents between dipole and quadrupole magnets, which keeps the betatron operating point at a certain place. This can be removed by adoption of a combined function lattice. The design, however, is

Table 1 Main Parameters of the Synchrotron

Maximum Energy	250 MeV
Circumference	23.9 m
Radius of Curvature	1.9 m
Maximum Magnetic Field (Center)	1.28 T
Lattice Structure	OFDFO
Operation Point	(1.70, 1.75)
Bending Angle of the Magnet	60°
n-values	-5,855(F), 6.164(D)

very difficult because of the lack of flexibility. After the real fabrication of combined function magnets, there is little possibility of adjustment and if the initial design is not so good, the machine is anticipated not to work at all. So it is inevitable to establish a good reference design to adopt this type lattice. For such a purpose, we have been developing a combined function proton synchrotron as illustrated in Fig. 1. The main parameters of the synchrotron is listed up in Table 1. So as to realize the design operating point, a three-dimensional magnetic field calculation has been performed with use of a computer code TOSCA[3]. In Fig. 2, the shape of the combined function magnet calculated by TOSCA is illustrated. The operating points at various excitation levels have been estimated from the calculated field distributions as shown in Fig. 3[4]. The magnetic field measurement is also to be performed with use of triple axes Hall-probe and similar investigation of the operating points will be applied using the real measured data.

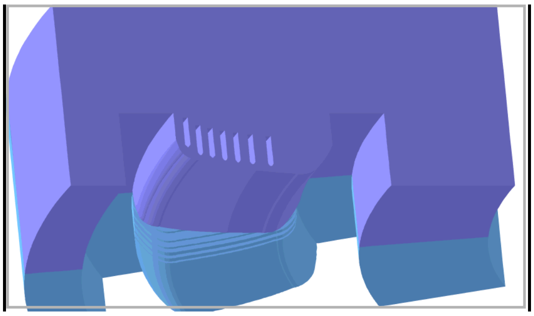

Fig. 2 Shape of the combined function magnet

3 UNTUNED RF CAVITY

The other item difficult to operate ion synchrotron is the RF accelerating cavity, because its resonance frequency must be changed according to the acceleration of the ion beam. The ordinary RF cavity tunes its resonant frequency with the revolution frequency of the ion beam or its higher harmonics,which needs rather complicated control of the bias current of the order of 1000A in the windings around the ferromagnetic material. The necessary accelerating voltage is proportional to the product of the ring circumference, radius of curvature and time derivative of guiding magnetic field. So the voltage for the small proton synchrotron dedicated for cancer therapy is rather low as several hundreds volts. Then an untuned RF cavity has been adopted for the medical synchrotron. If the RF power can be supplied by a solid state amplifier, the operation and maintenance is expected to become much easier. The conventional power feeder couples all the magnetic cores together with a single loop or a couple of loops in case of push-pull operation. The supplied power, however, is usually reflected so much due

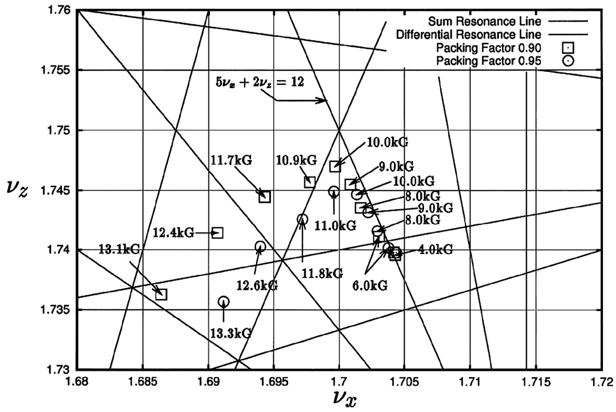

Fig. 3 Estimated operating points from the 3-dimensional calculation of the magnetic field.

to impedance mismatch because the input impedance of the cavity is usually much larger than the output impedance of the solid state amplifier of 50 Ω. In order to improve this situation, a new power coupling method called multifeed coupling has been invented, which couples every magnetic core through an individual loop driven by each amplifier as shown in Fig. 4[5]. The method is applied to an untuned cavity developed as a model for proton-cancer dedicated synchrotron. In Fig. 5, anoverall view of the fabricated untuned cavity is shown. The cavity has been powered with a solid state amplifier and the effectiveness of the new multifeed coupling has been realized as shown in Fig. 6. It can attain the factor 1.5~2 times higher gap voltage than the conventional method[6]. With this cavity applying new power feeding, we can attain the gap voltage higher than 1kV with supplied RF power of 1.5kW, which is enough for our requirement for the cancer therapy machine.

4 Formation of Enlarged Irradiation Field

As the method to enlarge the irradiation field, a combination of scatterer and a wobbler or double scatterer have been used so far. The beam utilization efficiency,

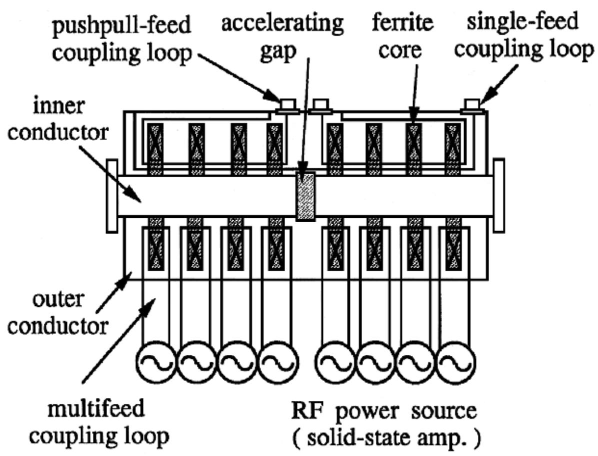

Fig. 4 Multifeed coupling method for power feeding.

Fig.5. Fabricated untuned RF cavity.

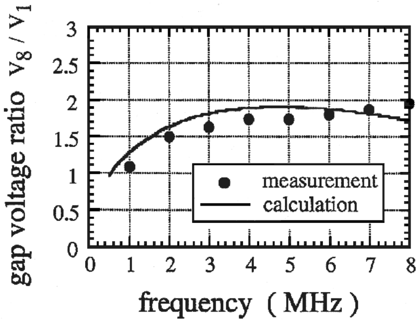

Fig. 6 Gap voltage relation between the multifeed coupling and the conventional one.

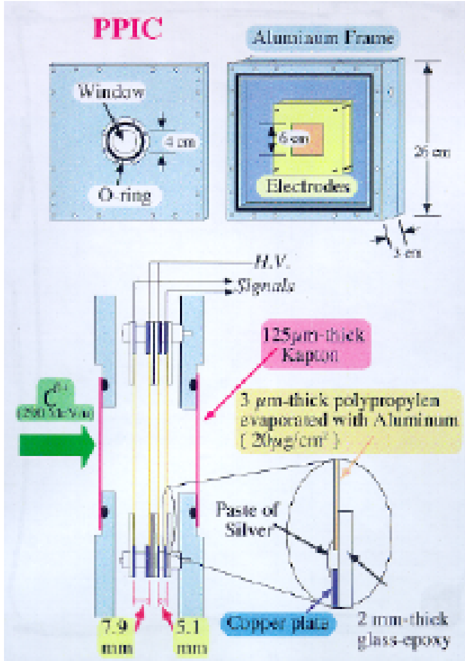

Fig. 8 Fabricated PPIC for observation of time structure of the extracted beam.

however is not so high for these methods. Further, it is difficult for these methods to realize fine dose distribution, which is needed for the case where the tumor locates rather close to an important organ. Recently, in Europe, a trial of irradiation field formation by a scanning of pencil beams has been started for cyclotron and synchrotron facilities at PSI and GSI, respectively. The main difficulty of applying this method for the beam from the synchrotron is due to the fact that the slowly extracted beam has a time structure as shown in Fig. 7. In order to realize a uniform dose distribution with a scanning of a pencil beam having such time structure, we are developping a system to adjust the scanning speed according to the beam intensity.

For the above purpose, we have developed a almost nondestructive beam monitor composed of a parallel plate ionization chamber (PPIC) as shown in Fig. 8. Its performance has been tested at HIMAC of NIRS comparing with the output from a scintillator(called Ripple Monitor). By such measurement, it is shown that the PPIC has a time response up to several kHz for the

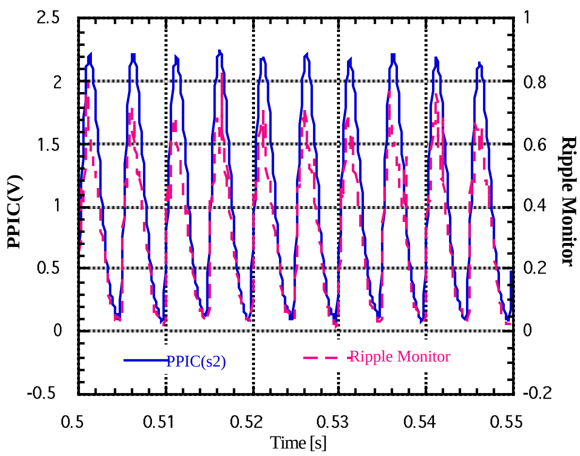

Fig. 7 Observed time structure of the extracted beam by PPIC and a scintillation counter(Ripple Monitor) at HIMAC.

intensity range of 10^6~10^9 pps for full-stripped (6+) carbon beam. Such scheme of speed control of the scanning magnets is under way to be applied to a newly constructed irradiation system at HIMAC with use of scanning of a small beam.

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