PROTON THERAPY ACCELERATOR PROJECT AT KYOTO UNIVERSITY

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Abstract

Accelerators for particle therapy have been studied at Kyoto University. Proton therapy is the first step. Compact accelerator design has been tried in the cases of a linac and a synchrotron. In both cases the existing 7MeV linac may be used as a first stage or a prototype of the injector. A compact synchrotron which can be used for both proton therapy and synchrotron radiation source has been designed. A synchrotron which accelerates the negative hydrogen ion is also discussed.

Introduction

A multi-purpose meson factory project which includes proton and pion therapy has been proposed at Kyoto University as a common use facility[1]. The design study of a compact linear accelerator for this project has been performed many years. A 7MeV proton linear accelerator has been constructed as a prototype of the first stage of the proposed linac at Uji Campus. But the total project is not funded yet.

Meanwhile, at the Research Reactor Institute of Kyoto University where the slow neutron capture therapy has been carried out recent years, the medical group is planning to construct a proton therapy facility in connection with the reformation of the Institute.

Thus we have recently discussed the proton therapy facility as the first step of the future project.

Comparison of the accelerators

The energy of the proton beam for the cancer therapy is 70MeV to 250MeV depending on the location of the tumors. The beam intensity is about 10nA for the proton accelerator dedicated to the therapy. Such low intensity machine should be smaller and less expensive than usual multi-purpose machines. Therefore it is necessary to develop new concepts of the dedicated machine.

A compact 230 MeV cyclotron with a room temperature magnet is designed at IBA, Belgium company[2]. This must be a good candidate though it is not yet constructed. Superconducting synchrocyclotrons have been also designed by H.G.Blosser[3] and by Sumitomo Heavy Industries[4]. In the cyclotron cases, we may purchase them from the companies.

The linac version is also proposed at Los Alamos[5] and Kyoto[6]. The low intensity linac can be operated at higher frequency more than 1 GHz with a small duty factor which means small power consumption. The main parameters of our proposed machine are listed in table 1. Fig. 1 shows a conceptual drawing of the 1300 MHz DTL cavity. This may be an extension of our 7MeV linac. The small-duty low-cost linac must be attractive because the linac is simple for operation[10].

The synchrotron became the first dedicated machine at Loma Linda University Hospital. In our present case, the existing 7MeV linac may be used as an injector of the compact synchrotron. Moreover the injector linac can be extended to the multi-purpose linac independently from the synchrotron. Therefore the compact synchrotron version has been mainly studied.

Table 1 Main characteristics of 250 MeV proton linac

cavity length	RFQ	DTL-1	DTL-2
cavity length	2m	7m	36m
RF frequency	433 MHz	433 MHz	1300 MHz
accel. field E_0		6 MV/m	9 MV/m
transit time factor		0.8	0.8
synchronous phase		30°	30°

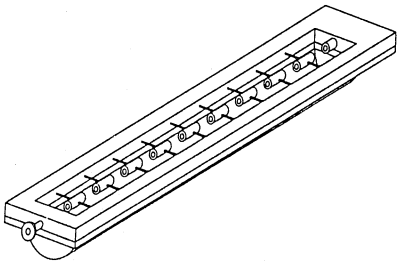

Fig. 1. a conceptual drawing of the 1300MHz DTL cavity.

Concepts of the compact synchrotron

The injector for the synchrotron is the 7MeV linac in our case. As the peak current of the linac is $10\sim50$mA, it is almost enough to use single turn injection scheme with repetition of 1Hz to get the average current of 10nA.

The combined type or the edge focusing type synchrotron may be compact but it is diffecult to adjust appropriate tunes because the edge effect becomes relatively large in the small ring comparing to the large ring. And the edge effect varies with the magnetic excitation. Thus we abopt the separate function type ring.

The main parameters of the proposed synchrotron are listed in table 2.

The ring has four arcs, but the periodicity of the magnetic lattice is four or two. In the usual proton acceleration the periodicity of four is chosen, but the superperiodicity of two may be chosen in the case of electron storage for synchrotron radiation (SR). The latter option is attractive if we construct the accelerator at the multi-disciplinary institute. The 250MeV proton ring corresponds to the 700MeV electron ring. Therefore the same ring can be used as a compact SR ring. In this case the C-type dipole magnet is preferable to the H-type one. The 90° C-type laminated core magnet is a little difficult to be fabricated. One of the examples of the plan view of the ring is shown in Fig.2, and the typical beta functions and dispersion are shown in Fig.3. Detailed orbit analyses are described in another paper7).

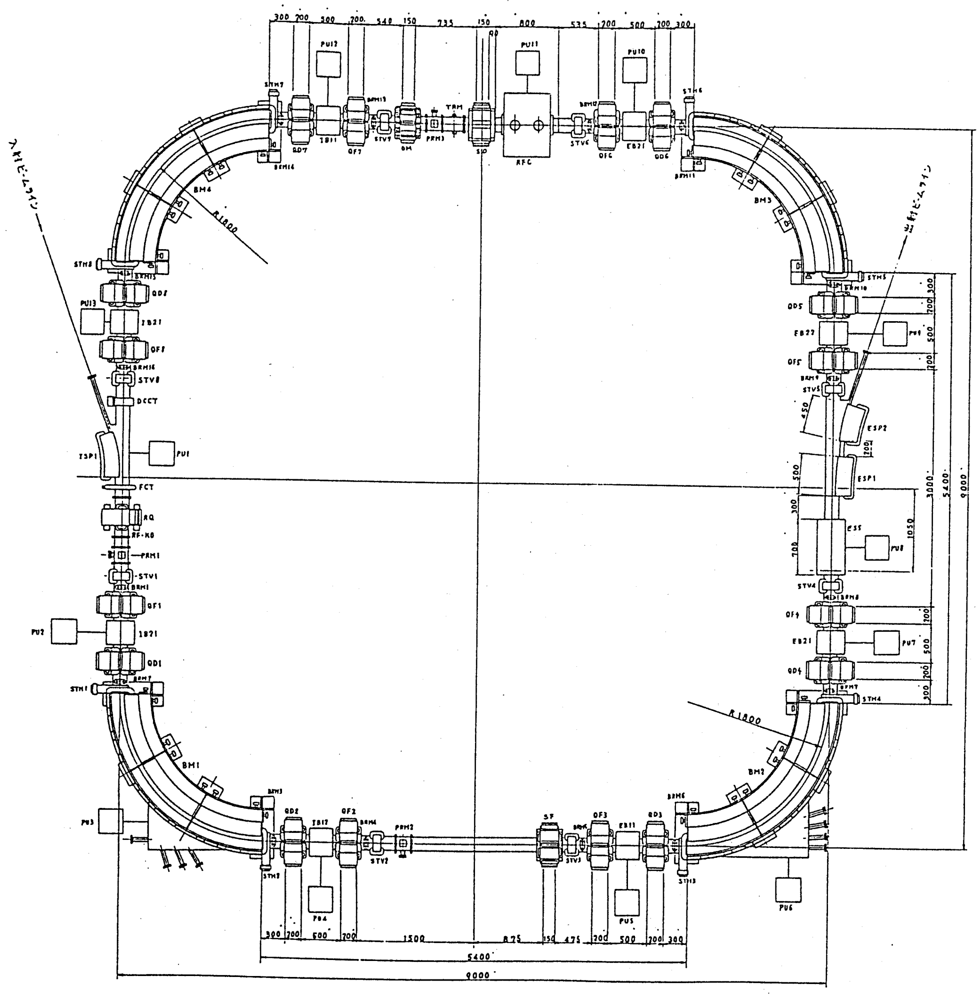

Fig.2 A plan view of the proton therapy synchrotron

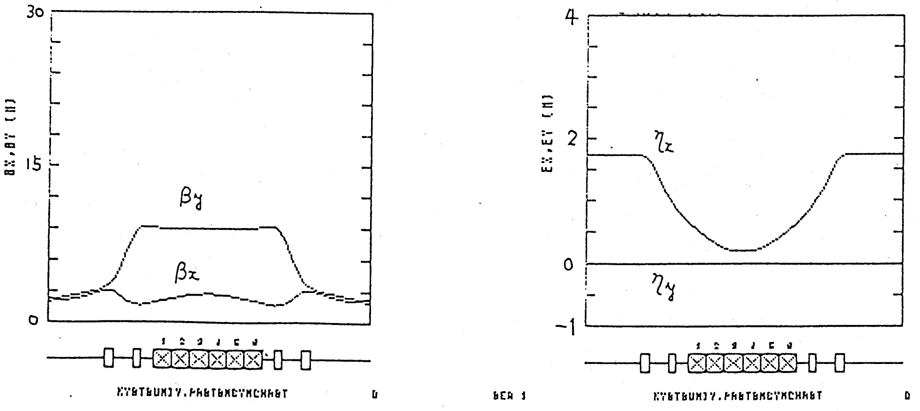

Fig.3 Lattice functions of the synchrotron

Table 2 Main Parameters of Medical Proton Synchrotron

Energy Region	
Injection	7 MeV
Extraction	100-250 MeV
Repetition Rate	0.5 Hz
Circumference	32.91 m
Focusing Structure	FDDF
Length of Long Straight Section	5.4 m
Number of Betatron Oscillations	
Horizontal Direction	2.2
Vertical Direction	1.15
Transition Energy	2.87 GeV
Bending Magnet (Without Edge focusing)	
Radius of Curvature	1.8 m
Length along the Beam Orbit	2.827 m
Bending Angle	90 deg
Field Strength	
Maximum (at 250 MeV)	1.35 T
Injection (at 7 MeV)	0.21 T
Quadrupole Magnet	
Length	0.20 m
Maximum Field Gradient (QF)	8.3 T/m
(QD)	7.3 T/m
RF Acceleration System	
Frequency Range	1.11-5.59 MHz
Cavity	Ferrite Loaded Untuned Re-entrant Cavity
Energy Gain per Turn	135 eV
Peak RF Voltage	400 V
Acceleration Time	0.5 s
Scheme of Extraction	1/3 Resonance
Beam Spill Time	0.95 s
Beam Intensity	7×10^{10} ppp

The H^- synchrotron

The H^- synchrotrons are proposed as the proton therapy machine[8)]. The main advantage of the H^- synchrotron is an easy extraction of the beam using a stripping foil. And the extracted beam are delivered simultaneously to several beam courses. Moreover the emittance of the extracted beam becomes small and the intensity of the extracted beam can be monitored and therefore stabilized by measuring the current of the electron stripped from the H^- ions. The disadvantage is that a weak field of 5.6kG at peak and good vacuum of 10^{-10} Torr are required to accelerate H^- ions up to 250MeV, which causes a relatively large ring diameter. The TARN II at INS. Tokyo University which has been developed as a heavy ion synchrotron is very suitable to accelerate H^- Ions up to 250MeV. Thus the TARN II-like ring and the 7MeV linac with the H^- ion source is another candidate of the proton therapy accelerator.

The second step of the project

At Kyoto University the meson therapy is considered to be the second step. We are now discussing several types of accelerators as the second step; linac, linac and rapid cycling synchrotron, linac and FFAG synchrotron etc. As for the linac the disk and washer (DAW) type cavity has been developed[9)]. In any case the 7MeV injectorlinac can be used as the first stage.

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