Compact Cotangential Orbit Accelerator for Proton Therapy

HITACHI
Inspire the Next

*Takamitsu Hae, Takamichi Aoki, Chishin Hori, Yuto Nakashima, Fumiaki Noda,
Takayoshi Seki, Kazuo Hiramoto, Hitachi, Ltd., Japan

Introduction

- A new type accelerator with a unique cotangential orbits has been proposed for particle beam therapy (PBT) system.
- The accelerator is being developed in Hitachi to realize the followings required for the PBT system,
  - ✔ Compact accelerator and less footprint
  - ✔ High beam intensity in all energy range
  - ✔ High speed beam energy change

Distribution of Orbits and Magnetic field

- The orbits are decentered to create the orbit-concentrated region including orbits of 70 MeV to 225 MeV.
- The horizontal tune is set to near 1 for half-integer resonance extraction.

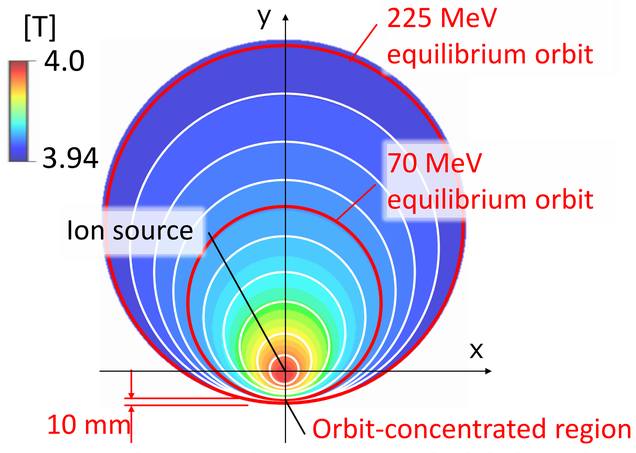


Fig. 1 Orbits and Magnetic field distribution.

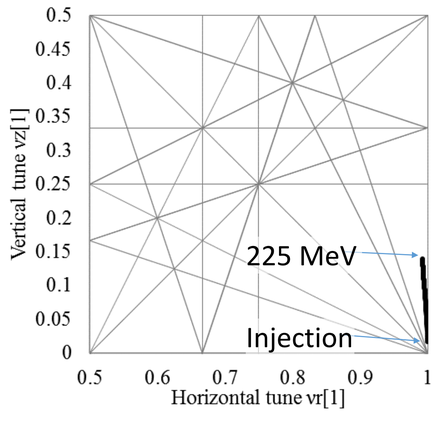


Fig. 2 Tune diagram.

Accelerator System

- The accelerator basically uses a weak focusing DC magnetic field and a frequency modulated RF acceleration.
- The superconducting magnet is applied to downsize the accelerator.

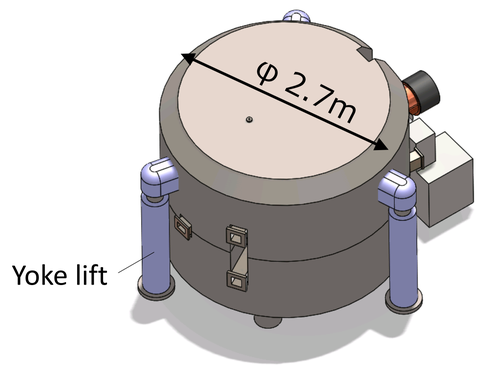


Fig. 3 Schematic drawings of the accelerator (Outline).

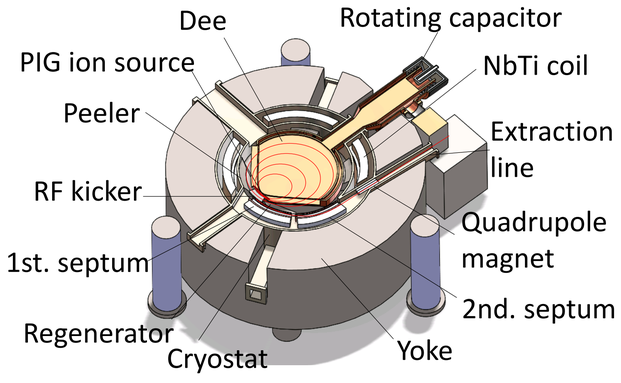


Fig. 4 Schematic drawings of the accelerator (cross-sectional view).

Table 1: Target specifications.

Items	value
Diameter of yoke	2.7 m
Total weight	60 t
Magnetic field	4.0 T to 3.94 T
Main coil	NbTi cable, conductive cooling
Magnetomotive force of main coil	1.8 MA
Harmonic number	1
RF frequency	61.0 ~ 48.5 MHz
RF voltage, required power	10 kV, 30 kW
Extracted beam energy	70 MeV to 225 MeV
Extraction method	Slow extraction without degrader
Pulse repetition rate	< 500 Hz

Beam Extraction

- A new extraction method utilizes followings located nearby the orbit-concentrated region.
  - ✔ Transverse RF kicker
  - ✔ Peeler and regenerator magnetic fields
  - ✔ pulse septum magnets

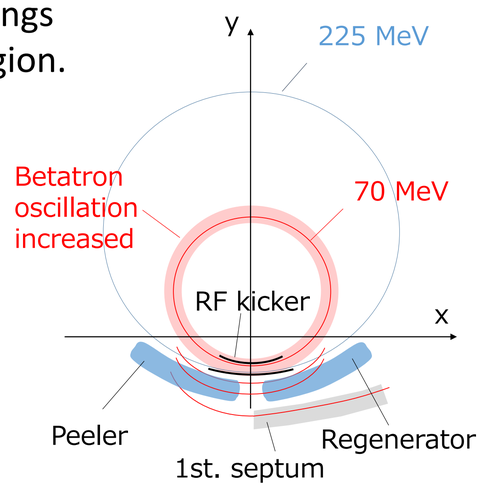


Fig. 5: Schematic drawing of the new extraction method

- The extracted beam can be controlled as follows,

Items	controlled by
Energy	Application time of V_{rfac}, without degrader
Pulse width	Application time of V_{rfk}
Current	V_{rfk} and / or its frequency

f_{rfac}: Frequency of RF accelerating voltage
V_{rfac}: RF accelerating voltage
I_{sep}: Excitation current of septum magnet
V_{rfk}: RF kicker voltage
I_{scan}: Excitation current of scanning magnet
I_{beam} : Extracted beam current

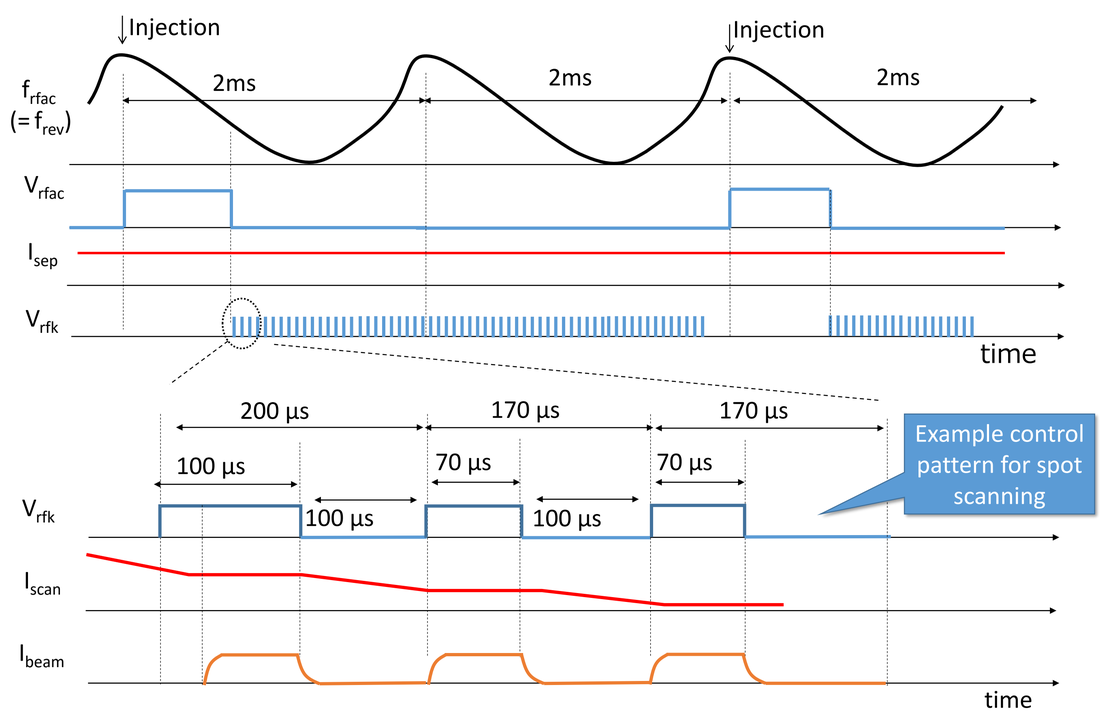
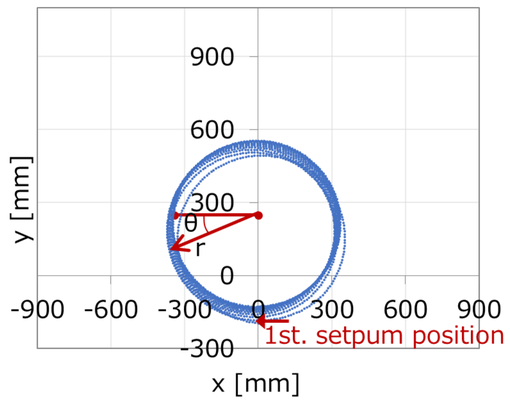


Fig. 6 Timing chart of the beam extraction

3D Tracking Analysis of Beam Extraction

- The single particle tracking analysis with 4th order Runge-Kutta method.
- The minimum turn separation of 11 mm can be obtained in the extraction energy range.



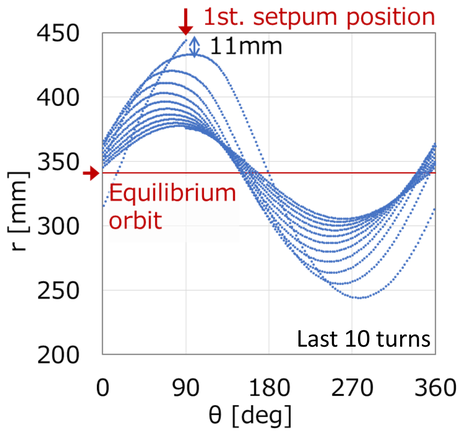
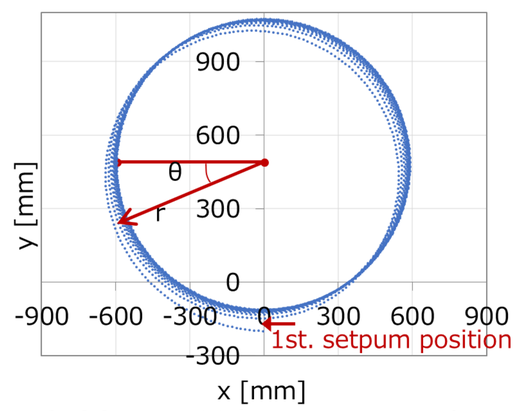


Fig. 7 70 MeV beam extraction, applied only Vrfk = 2 kV, and the initial particle position of +1 mm horizontally displaced from the equilibrium orbit.



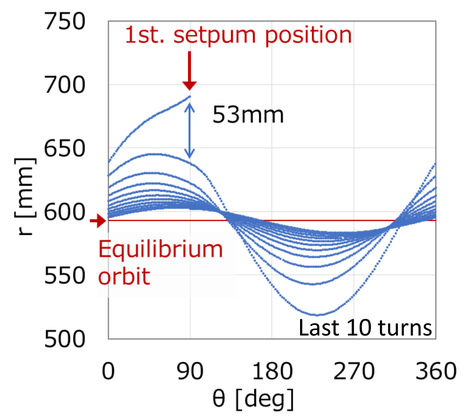


Fig. 8 225 MeV beam extraction, applied only Vrfk = 2 kV, and the initial particle position of +1 mm horizontally displaced from the equilibrium orbit.

Conclusions

- The conceptual design has been done for the cotangential orbit accelerator that adopts the new extraction method utilizing combination of cotangential orbits, RF kicker, and peeler and regenerator.
- The tracking simulation indicates that it is possible to extract 70-225 MeV proton beam without using a degrader.
- The detailed design is now in progress to achieve accurate dose control suitable for a scanning irradiation with compact accelerator.