H⁻ CYCLOTRON FOR CHARGE-EXCHANGE INJECTION INTO A SYNCHROTRON

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A 12 *MeV* three-sector cyclotron-injector with pulsed extraction of a pure H^- beam and pulsed operation of the RF system is described. For extraction, a partial compensation of the magnetic field along the extraction trajectory is produced with a pulsed magnetic system operating at a 10 *Hz* repetition rate and 1 *msec* duration. Due to the pulsed mode of operation, the consumed RF power does not exceed 1 *kW*. Two variants of injection are considered: external injection through a channel in the pole of the magnet at a 30° angle to the mid-plane, and internal injection making use of a three-channel water steam H^- ion source. The cyclotron is intended to be part of a multi-purpose medical facility for radioisotope diagnostics and proton cancer therapy.

INTRODUCTION

At the end of 1980's - beginning 1990's at BINP there was began the development of instrumentation for the proton and γ-therapy of a malignant tumours. The basis of this subject is the development of the relatively low cost compact accelerator complex for the proton therapy (Compact Proton Therapy Facility) which could be located in the vicinity of existing oncologic centers with the modern advanced diagnostic and γ-therapy. Schematic diagram of the complex is given in Figure 1.

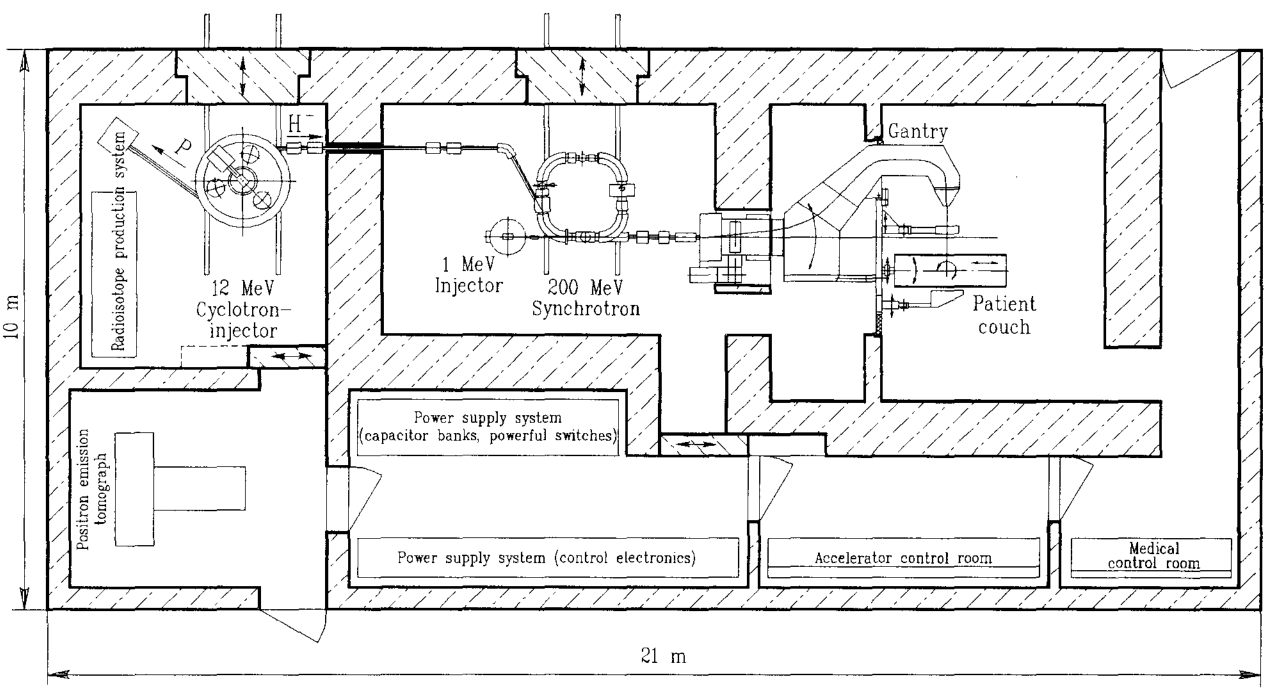

Figure 1 : Accelerator complex layout.

The complex comprises a 200 *MeV* small proton synchrotron with the pulse field of 5 *Tesla* [1], a compact pulse gantry [2] providing the dynamic method of irradiation from various sides, a 1 *MeV* electrostatic tandem proton injector for multiturn injection into synchrotron (first stage of the work) and 12 *MeV* cyclotron (second stage of the work) which is planned to be used by double way:

- H^- source for charge exchange injection into synchrotron. H^- beam extraction by means of pulse magnetic extraction system.
- Production of short-life-time isotopes for positron emission tomography. H^+ beam extraction by means of electrostatic septum and recharge stripping target.

DESIGNED CYCLOTRON PARAMETERS

Energy	12 *MeV*
H^- beam pulse extraction mode	
Peak current	1 *mA*
Pulse duration	0.1 *msec*
Repetition rate	10 *Hz*
H^+ beam extraction mode	
Repetition rate	50 *Hz*
Duty factor	20
Pulse duration	1 *msec*
Peak current	1 *mA*
Average current	50 *μA*

MAGNETIC SYSTEM

Geometry	3×60° poles magnet
Outer diameter	1.6 *m*
Height of magnetic yoke	0.6 *m*
Weight	14 *tonnes*
Radius of extraction	0.4 *m*
Maximum field	2 *Tesla*
Minimum field	0.3 *Tesla*
Consumed power	4 *kW*

RF-SYSTEM

Type of cavities	λ/4
Number of cavities	3
Frequency	63 *MHz*
Voltage on duants	30 *kV*
Consumed power	
Continuous mode	20 *kW*
Pulse mode operation with duty factor 20	1 *kW*

INJECTION

At present time two variants of injection are under consideration:

- ***External version:***
  external injection with preacceleration up to 150 *kV* by two-gaps buncher. Beam is injected at angle of 30° to middle plane through channel in magnetic pole and then is

bent by electrostatic deflector (Figure 2). Plasma-surface cesium H^- ion source with Penning geometry of discharge (the same as for operating electrostatic proton injector) is planned to be used in first stage of experimental investigation. An advantage of external version is a possibility to use various ion sources in future.

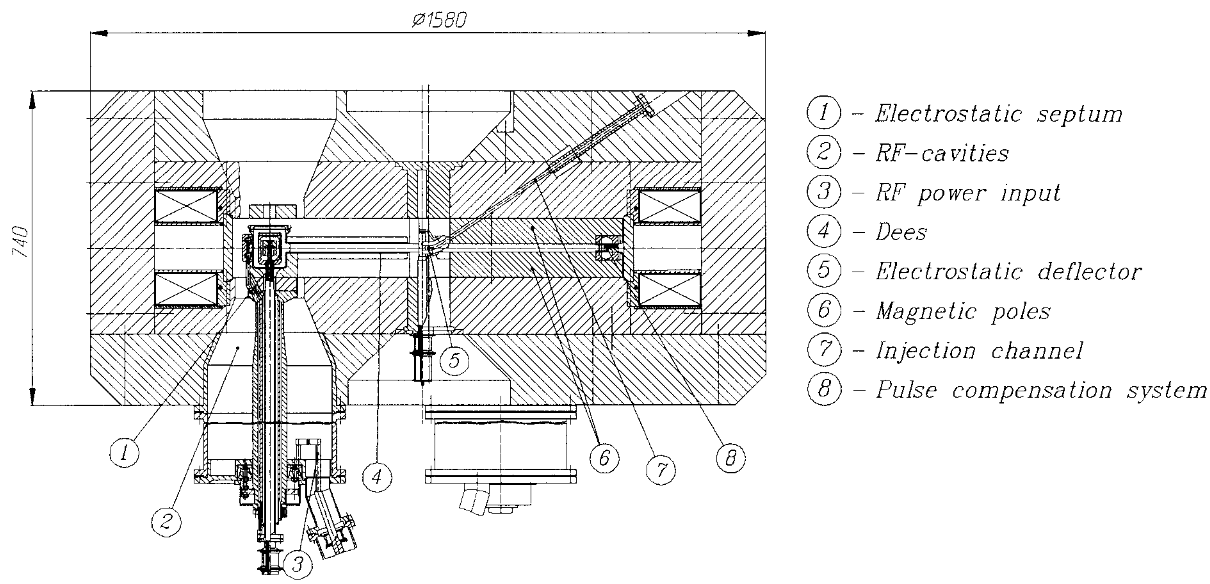

Figure 2 : Azimuthal cross-section of cyclotron (external injection version).

- ***Internal version:*** three-channel water steam H^- ion source located in cyclotron center (Figure 3) operating in pulse mode with high beam pulse current is used [3]. Internal version is more simple since it uses for ion generation internal cyclotron magnetic and electric fields and no needs for transport injection line, but it could be more hard in comparison with external version to increase ion current if it will needs. However, internal injection version meet the requirements on ion current for charge exchange injection into constructing synchrotron (see *Appendix*).

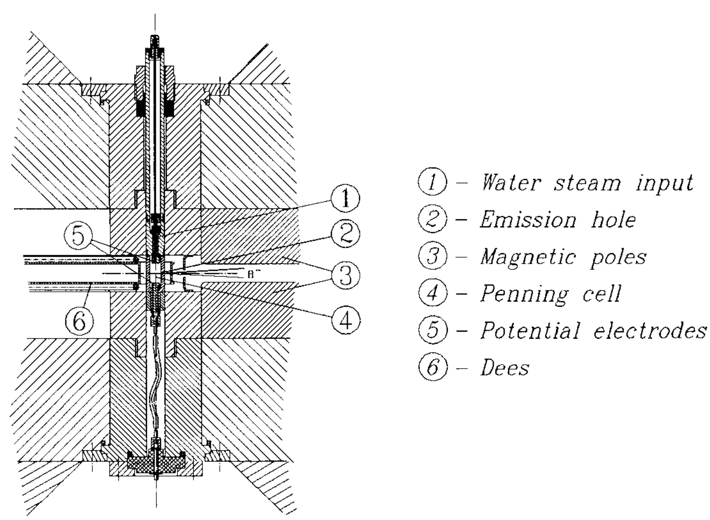

Figure 3 : Cyclotron central part azimuthal cross-section (internal injection version).

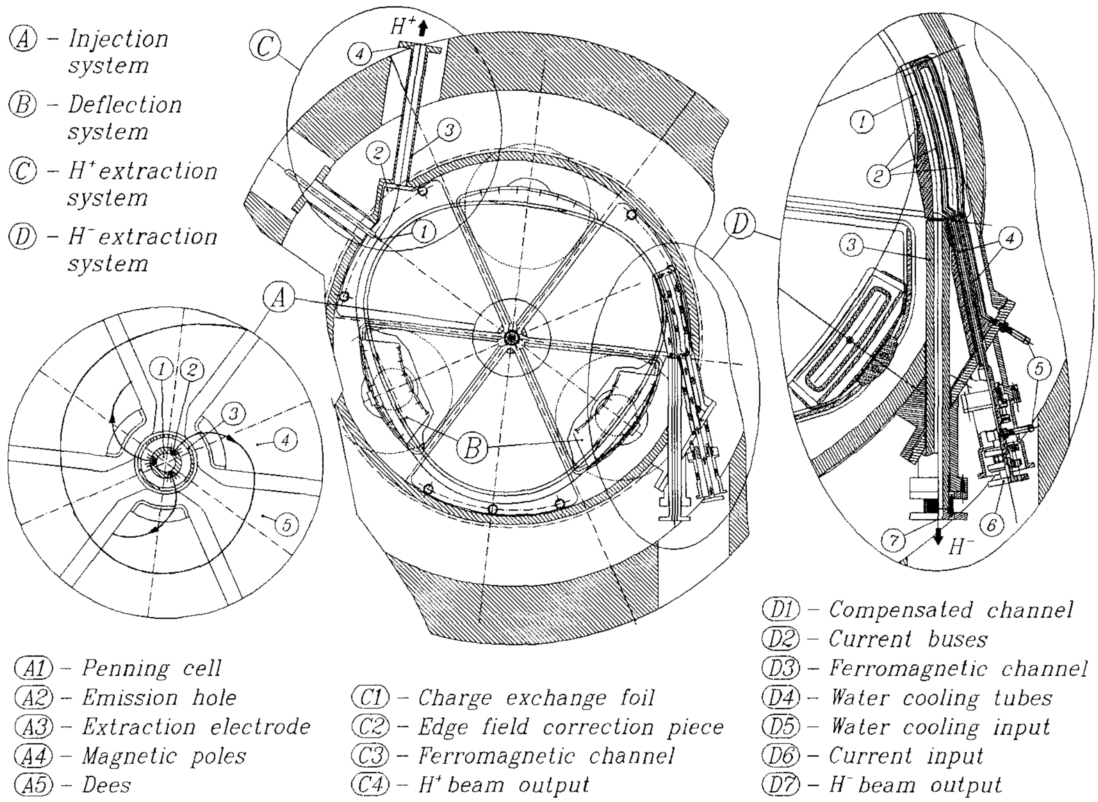

Figure 4 : Cyclotron injection (internal version) and extraction systems

EXTRACTION

As it was mentioned above, the cyclotron allows to extract H^- or proton beam. Radial cross-section of the cyclotron extraction systems are shown in Figure 4. For preliminary H^- beam deflection there are used electrostatic septums in both cases. The septum is located inside of dees (Figure 5), high voltage input is displaced inside of RF cavity central tube. Two of three dees contains electrostatic septum.

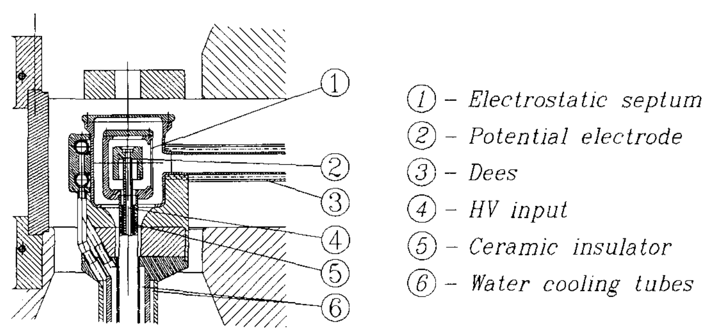

Figure 5 : Electrostatic septum and high voltage input cross-section.

- ***H^- beam pulse extraction mode:*** partial compensation of the magnetic field along the extraction trajectory by pulse magnetic system (Figure 4,D). It comprises a laminated steel insertion in cyclotron poles and three current buses forming two rectangular apertures (Figure 6). The system is fed by special

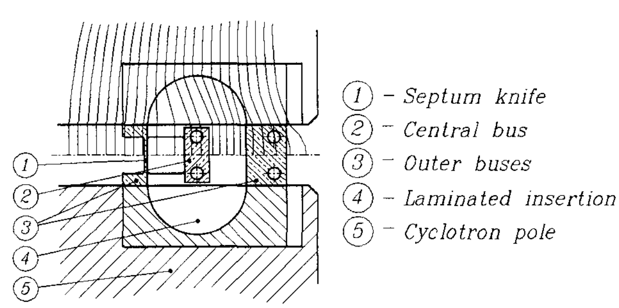

Figure 6 : Pulse extraction system cross-section and magnetic flux

generator which provides current pulse of near trapezoidal waveform. In the time of extraction pulse magnetic field subtracts from main field in working aperture and adds to main in other one. Speaking in other terms, the system operates as magnetic flux commutator, redistributing the flux between two apertures in the time of extraction To direct beam into pulse magnetic extraction system only one of two electrostatic septums is under operation.

- ***H^+* beam extraction mode:**
  extraction of the proton beam by means of stripping of H^- ions at carbon foil disposed behind trajectory of pulse extraction (Figure 4,C). To direct beam to stripping foil both electrostatic septums are under operation.

APPENDIX

The implementation of charge exchange injection into compact synchrotron is not a trivial task because of small length of straight sections. So a compact combined magnet for radial injection was designed (Figure 7). A peculiarity of the magnet is the fact that septum and bump magnets are fed separately to provide a small radius of the H^- beam trajectory.

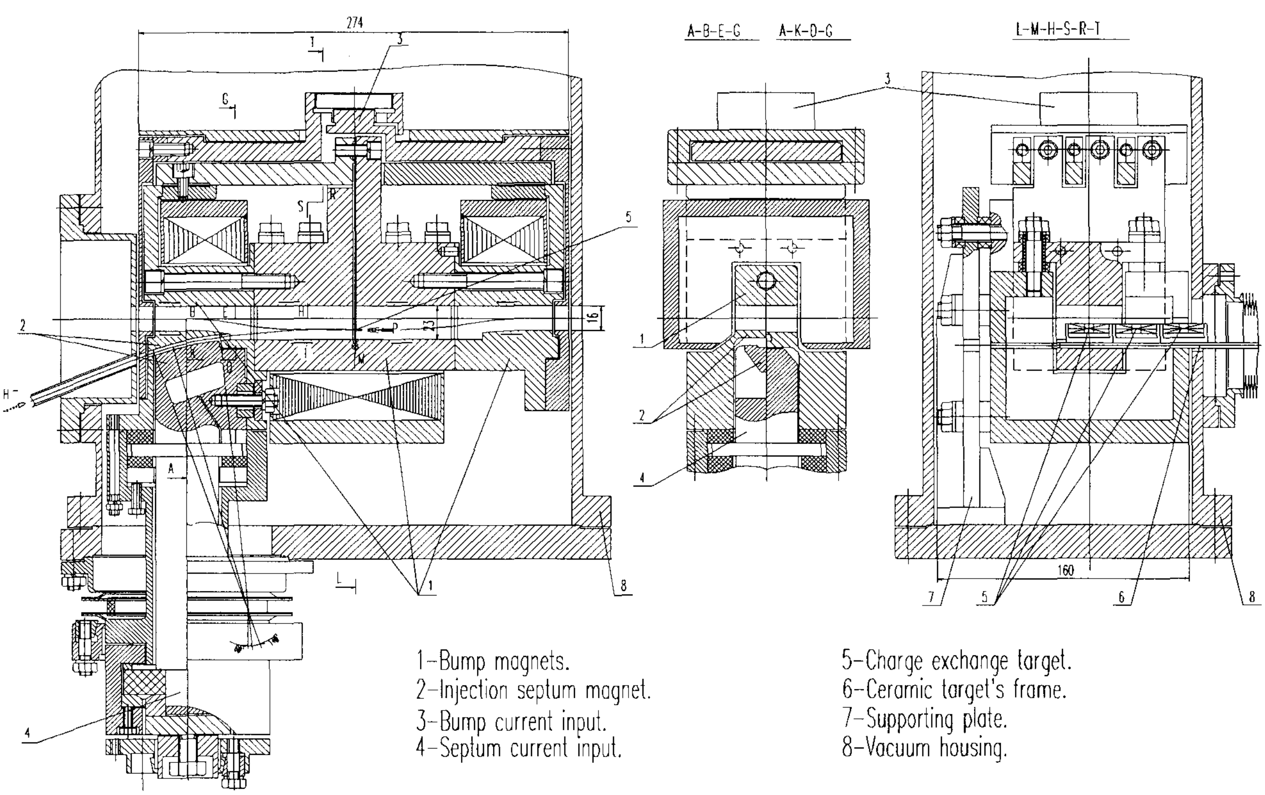

Figure 7 : Charge exchange injection system into compact proton synchrotron.

A requirement exist on beam intensity for proton therapy that it must not be lower then 10^{11} particles per second to ensure irradiation time in bounds of few minutes. In order to specify the requirement on H^- current from the cyclotron there was carried out numerical simulation of charge exchange injection into synchrotron. The rezults of this calculations are presented in Figure 8, Figure 9. One can see that injection current of 1 *mA* is quite enough to accumulate $1.8 \cdot 10^{11}$ particles with injection of time 40 μs. Such a value exceeds more times the requirements on dose intensity, taking into account the fact that repetition rate is equal to 10 *Hz*.

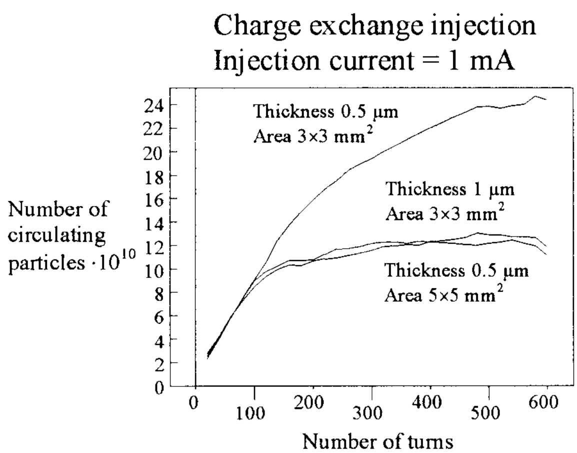

Figure 8 : Dynamics of injection with various parameters of charge exchange target.

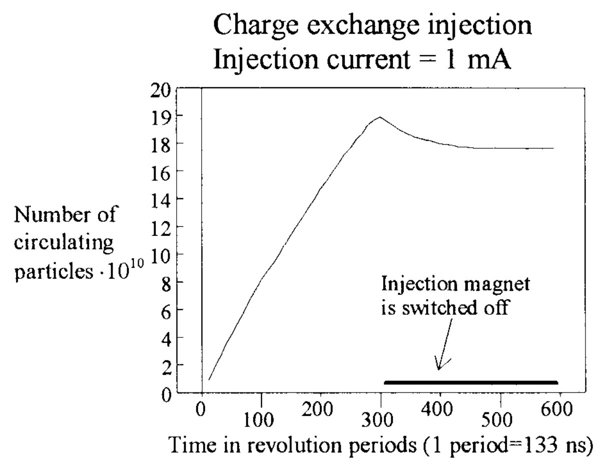

Figure 9 : Dynamics of particle accumulation with injection time of 40 *μs*

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[3] P.Kuznetsov, V.Parkhomchuk and G.Silvestrov, ***Multi-channel Water Steam H⁻ ion Source for Internal Injection into Cyclotron*** - this conference.