DEVELOPMENT OF LINEAR ACCELERATORS AS INJECTORS FOR MEDICAL ACCELERATORS IN IHEP-PROTVINO

Yu.A. Budanov, O.K. Belyaev, I.A. Zvonarev, A.P Maltsev, E.V. Mazurov, S.A. Strekalovskyh, V.A. Teplyakov
State Research Center of Russia Institute for High Energy Physics, 142281, Pritvino, Moscow Region, Russia

INTRODUCTION

Advantage of use of the accelerated ions to the medical purposes has been proved in the middle of the last century. However, only recently this idea began to be used widely in applied medicine. It became possible owing to qualitative development of accelerating technique. An essential role in invention and a practical realization of acceleration and focussing of ions in systems with high-frequency quadrupole focussing (RFQ) here has played. In IHEP first-ever such accelerator has been implemented, and then some more various accelerators with RFQ [1] have been produced. RFQ application as an initial part of the accelerator now is applied in the in most cases of accelerators of ions to the medical purposes all over the world. In IHEP accelerators with drift tubes and simultaneous use of high-frequency focusing RFQ DTL also are developed and put into operation. Application RFQ DTL is practically realized for acceleration of protons up to 30 MeV [2].

Now in IHEP working on creation of two accelerators with use RFQ for the medical purposes are carried out. In the report theoretical calculations, sketches and design decisions for projects of these accelerators are submitted. The accelerator of carbon ions up to energy 286 keV/u is intended for injection of carbon ions in existing accelerator I-100 according to medical ion IHEP program. This accelerator will represent section RFQ with application of a special structure of electrodes and radio engineering division into two subsections, providing work of second subsection RFQ as debuncher. Other accelerator for protons with energy 5 MeV is planned as injector in the ring accelerator for the center of proton-beam therapy of Botkin's hospital (Moscow). The accelerator will consist of two sections, in first section is used conventional RFQ, in the second section the RFQ DTL structure is applied. Sections are planed on the basis of resonators with a longitudinal magnetic field.

ACCELERATOR FOR CARBON IONS

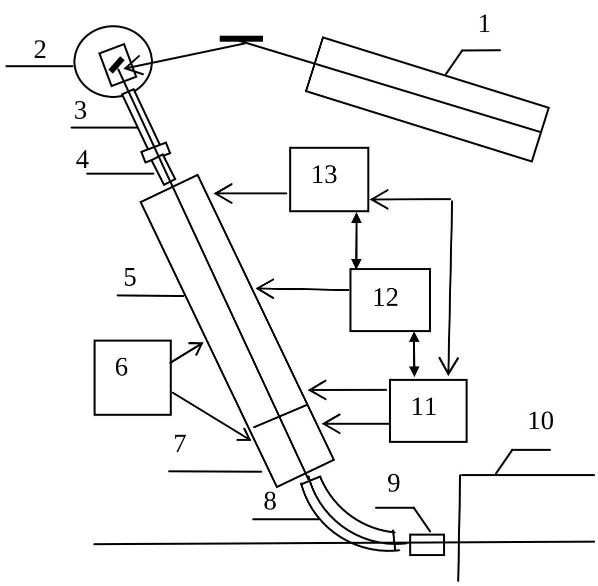
For acceleration of carbon ions it is supposed to use already existing in IHEP accelerators of protons - linear injector I-100 and then a booster proton synchrotron of IHEP. The existing scheme of protons injection in linear accelerator I-100 with application of the pulse transformer on 700 kV is difficult for combining with a simultaneous opportunity of injection of carbon ions received from a laser source. Therefore was accepted decision to develop the scheme of injection of carbon ions with the help of the special accelerator RFQ, established under an angle to a line of injection of protons. Such scheme possesses that advantage, that in it the opportunity of operative transition to a mode of acceleration of protons is kept. The basic technical requirements for RFQ are in tab. 1.

Table 1: Technical requirements

Frequency, Hz	1 Hz
Current impulse C^{+5}_{12}	6 mcsec
Current impulse C^{+4}_{12}	20 mcsec
Max. accelerated current C^{+5}_{12}	20 mA
Max. accelerated current C^{+4}_{12}	20 mA
Energy out	286 keV/u
Momentum spread, after deb	±1.1%
Norm. emittance @ 90%	0.5÷1 π mm mrad

Acceleration of carbon ions in I-100 will occur on the second frequency order. Carried out in 2000-2003 years experiments on acceleration on the second frequency order in I-100 ions with Z/A=1/2 (deuterons) have shown, that a mode of deuteron acceleration non-standard, distinct from a mode of acceleration of protons. Dependence of deuterons capture in acceleration from energy of injection appeared resonance-like with a maximum of capture at a voltage on preinjector V = 572 kV instead of V = 350 kV. (The reason of this effect is a penetration an electric field inside drift tubes on the first periods of acceleration.) At the same time the width of a capture curve at a level 0.1 from the basis equals to 20 kV. Hence, exit RFQ energy of carbon ions, per one nucleon, should be equaled W = (286±5) keV. Precise constraints of injection in I-100 dictate necessity of debuncher application on RFQ output. Debuncher is formed as a compartment separated from the basic volume of the resonator by a radio engineering partition. Debuncher is called to reduce momentum spread and to

enable to change in some limits average energy of particles on RFQ exit for option of capture of carbon ions in I-100 to a maximum.
The block diagram of injection is shown on Fig. 1.



1 – laser, 2 – target, 3 – drift, 4 – matching system for the beam before RFQ , 5 – RFQ, 6 – automatic frequency control, 7 – debuncher, 8 – magnet system, 9 – matching channel, 10 – I-100, 11 – RF system, 12 – automatic control system, 13 – technological systems.

Figure 1: The block diagram of injection.

RFQ accelerating system and debuncher are created on a basis 2H- resonator with the difference - planes of symmetry of the resonator are turned on 45º (so that planes of symmetry of focusing in RFQ and in I-100 coincided, Fig. 2).

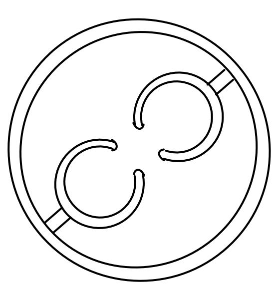


Figure 2: 2H – resonator sketch

The summary of basic physical parameters RFQ with debuncher is given in table 2. Let's notice, that debuncher represents section of RFQ with electrodes without modulation in the beginning and with specially matched modulation on the several periods on the RFQ exit.

Table 2: Parameter list of RFQ

Beam energy, in	100/3 keV/u
Beam energy, out	286 keV/u
RFQ voltage	97 kV
Debuncher voltage	116±20 кВ
Phase shift RFQ-debuncher	0±30º
Frequency	148.5 MHz
Max. E-field on surface	273 kV/cm
Energy spread without debuncher	10.7%
Energy spread with debuncher	4.5%
Bunch width	117.5º
Stable phase angle	-89º÷ -30º
Capture ratio	91%
Gap efficiency	0.0091÷0.25
Relative frequency of longitudinal oscillation	0.047
Trans. Phase advance	0.64
Norm. acceptance	1.5 π mm· mrad
Norm. Emittance @ 95% of beam and 0.39 π·mm mrad	0.52 πmm ·mrad

PROTON ACCELERATOR

Operation of a linear accelerator in structure of a medical complex shows special requirements to its reliability, operational safety and stability of parameters. For performance of these requirements at creation of the accelerator use of principles of construction, the technical and technological decisions which developed earlier and have been checked up at creation of accelerator URAL-30M which physical start-up has been carried out in 2007[3] is offered.

It is planned to construct structure of system of injection as follows (Fig. 3). The beam of protons from ion gun S go through the transport channel T1 containing adjusting and focusing elements and enter to accelerator.
For elimination of the probable dispersive effects influencing quality of a beam, refusal of injection “ under a corner ” is offered. Application of the linear injection with two magnetic lenses and diaphragms is offered. The accelerating structure will consist from initial (RFQ) and the basic of parts of the accelerator (RFQ DTL) with various systems of electrodes. After the energy of a beam is obtained, a beam through transport channel T2 passes in debuncher D for maintenance of required momentum spread.

Рис. 3 Sketch of injection

For compensation of acceleration rate reduction in RFQ DTL growth of a voltage on SH - the resonator on 13 % on length is provided. The maximum of electric field on a surface of electrodes does not exceed 300 kV/cm, that prevents occurrence of electronic loading. The small relative length of the accelerator sections (L/λ <1,5) results in absence of parasitic oscillations near of working mode in a spectrum of resonators.

In RFQ application 2H-resonator, and in RFQ DTL sector SH-resonator is planned. Both types of the resonator were already applied in IHEP, their photos are submitted on Fig. 4 and Fig. 5.

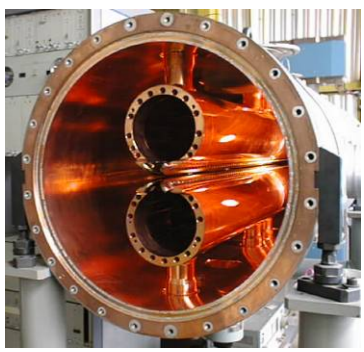


Figure 4: 2H-resonator

Application of the 2H-resonator is caused by absence in its spectrum close located dipole oscillations that takes place in frequently used four-chamber (4К-) resonators and demands acceptance of special measures for their elimination.

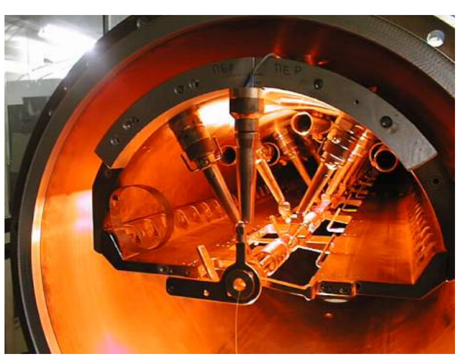


Figure 5: SH-resonator

In the tab. 3 results of an estimation of parameters are shown for the offered linear accelerator.

Table 3: Parameter list of the injector

Parameter	Value	
	RFQ	DTL
Beam energy, in, MeV	0.1	1.77
Beam energy, out, MeV	1.77	5.0
Current, мA	1÷10	1÷10
Voltage, kV	140	195
Max. E-field on surface, kV/cm	250	300
Stable phase angle	-90÷-30	-30
Frequency, MHz	148.5	148.5
Trans. Phase advance	1.0÷1.2	0.7
Norm. acceptance, mm ·mrad	7.5π	8.5π
Norm. Emittance @ in 0.7 π·mm mrad, current 10mA, mm ·mrad		1π
Q-factor	16000	13000
Number of periodes	91	27
Interval between RFQ DTL and debuncher, m	5	

CONCLUSION

In the report the opportunity of application structures with RFQ-focusing for medical accelerators of ions is shown. Structures for initial part (RFQ) and the basic part (RFQ DTL) are developed and manufacture by forces of IHEP. The specified structures have passed experimental check on created in IHEP installations URAL-30, URAL-30M, LUSI and others.

REFERENCES

[1] O.K. Belyaev et al, Proceed. of LINAC 2004, Luebeck, Germany, p. 285–287.

[2] Yu.A. Budanov et al, ICFA Beam Dynamics Newsletter, #36, 2005, p. 30–34.

[3] Yu.A. Budanov et al, Proceed. of RuPAC 2006, Novosibirsk, Russia, p. 273-275.