MATCHING THE PROTON BEAM BY MEANS OF INDEPENDENTLY PHASED BUNCHERS IN CYCLINAC CONCEPT

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Abstract

Nowadays a hadron therapy is one of the modern methods of a cancer treatment. For that purpose it is required that a proton beam, accelerated up to 250 MeV, penetrates on a depth about of 30 cm. It is known that linac, cyclotron and synchrotron can be used as a source of proton/ion beams. The main linac advantages are a high beam quality and a possibility of beam energy variation but, on the other hand, initial low-energy part of a linac is markedly expensive. Production of mentioned beams is possible on the base of a concept called CYCLINAC, when a commercial cyclotron is used as an injector, in which protons are accelerated up to 20-30MeV, for main linac. Matching the beam extracted from a cyclotron with a linac input is the main problem of this concept. It is caused by difference of operating frequencies of cyclotron and linear accelerator as well as a high phase size of a bunch from the cyclotron. It is proposed to use the system of independently phased bunchers for beam matching. The BEAMDULAC-CYCLINAC program is developed for simulation of the self-consistent dynamics of proton beams in a matching channel. Results of beam dynamics simulation for CYCLINAC will be presented and discussed.

INTRODUCTION

Due to the growth of cancer diseases it has recently become urgent task to develop effective methods of therapy with minimal side effects. Existing therapies such as surgery, chemotherapy, hyperthermia, radiotherapy is not completely effective in the treatment of deep-seated malignant tumours. With the development of technology accelerators, it became possible to create a complex proton and ion therapy. The expert community is actively discussing several options of implementing proton beam therapy systems. The main problem with these options is the choice of the initial part of such systems. In particular, in 1993, U. Amaldi proposed the concept of so-called CYCLINAC as the accelerator complex, in which the cyclotron used as injector in the linear accelerator [1]. Use of a PET-cyclotron for medical centres gives a significant economic effect. The most developed project concepts CYCLINAC are CABOTO [2], TULIP [3], ProTEC [4] and ProBE [5]. The main difficulty in the development of systems in accordance with the concept of CYCLINAC is the task of the transmission beam extracted from the cyclotron to the front-end of a linear accelerator, in view of the significant differences of operating frequencies of cyclotron and linac. In the present work it is compared two schemes of a beam transportation channel from the cyclotron on energy W to a linear proton accelerator energy of 250-300 MeV.

NUMERICAL SIMULATION RESULTS

At the beginning we consider a transportation channel based on three bunchers working at frequency 324 MHz that is in four times greater than cyclotron operation frequency. A schematic plot of the structure is shown in Fig. 1. It was assumed that particles continuously entered to transportation channel with average relative velocity equals to 0.248 and relative spread equals to 0.033. Beam current was presumed to be equal to 1 mA. The main transportation channel is presented in Table 1.

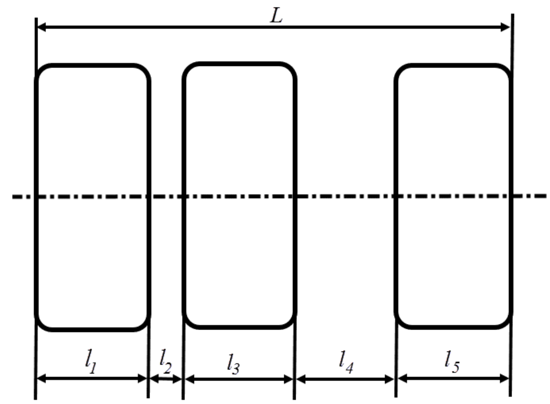

Figure 1: Layout of transportation channel.

Table 1: Main Channel Parameters

N	1	2	3	4	5
Length l, cm	34	1	16	31	16
E_{max}, kV/cm	170	–	175	–	170
Synchronous phase	$\pi/2$	–	$\pi/5$	–	$\pi/5$
Aperture, cm	5	5	5	5	5

It was obtained that the transmission coefficient was equal to 79.8% under bunch phase length equals to 2.43 (the physical length is about 6.5 cm). This bunch core conforms 70% of injected particles. Input (blue color) and output (red color) particle distributions in longitudinal phase space are presented in Fig. 2. Particle distributions in the transversal phase spaces are shown in Fig. 3 and Fig. 4. Particles spectra are shown in Fig. 5- 7. As one can see from Fig. 6 and Fig. 7 there is no significant beam envelope growth in channel without transversal focusing. In all mentioned figures blue objects are input and red are output. The above scheme allows one to decrease bunch phase width twice.

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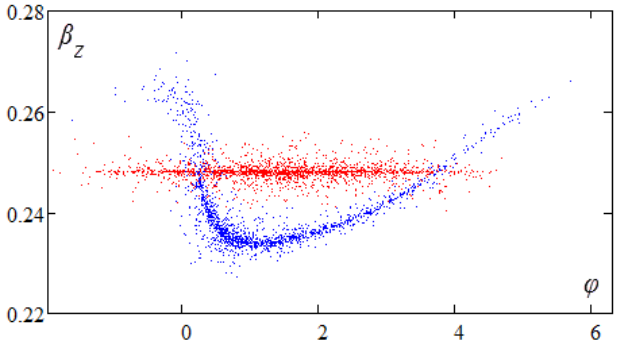

Figure 2: Longitudinal phase space.

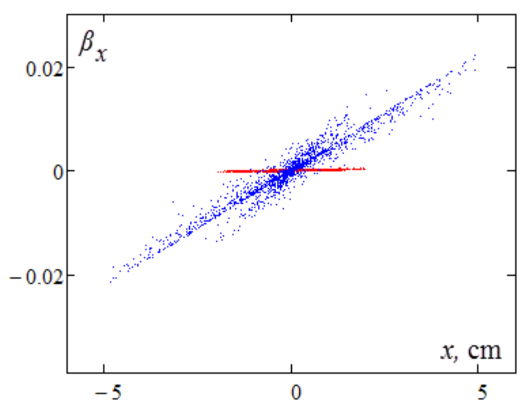

Figure 3: Transversal (x,β_x) phase space.

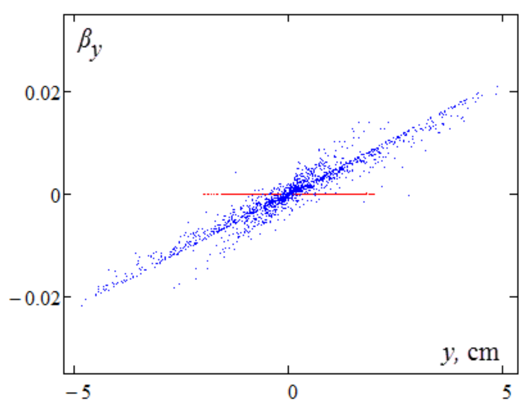

Figure 4: Transversal (y,β_y) phase space.

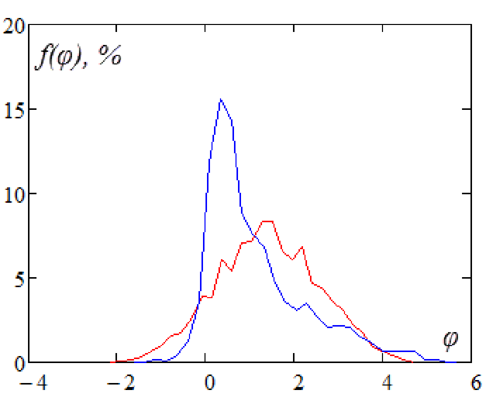

Figure 5: Particle distribution by phases.

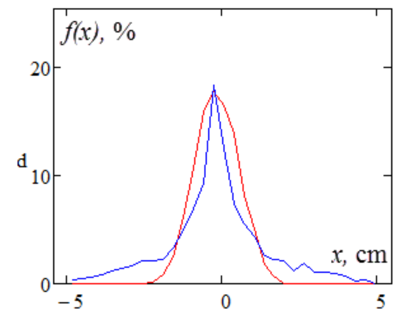

Figure 6: Particle distribution by the first transversal coordinate.

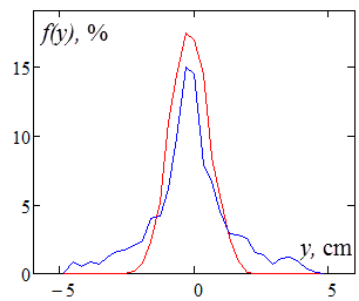

Figure 7: Particle distribution by the second transversal coordinate.

In view of improving the beam bunching quality as well as lowering particle losses in a linear accelerator, the next transportation channel scheme is proposed. This scheme consists of two resonator groups. Resonators into groups have different operating frequencies (see Table 2). A schematic plot of suggested structure is shown in Fig. 8 (the first group) and Fig. 9 (the second one). Operating frequency of the first group is 162 MHz and 324 MHz for the second one.

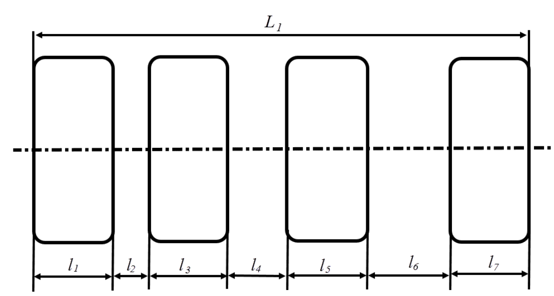

Figure 8: Layout of the 1st part of transportation channel.

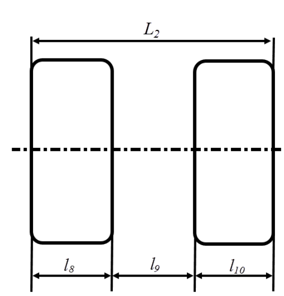

Figure 9: Layout of the 2nd part of transportation channel.

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Table 2: Main Channel Parameters

Resonators / Drift tubes										
	$\lambda = 185.2$ cm						$\lambda = 92.6$ cm			
N	1	2	3	4	5	6	7	8	9	10
Length *l*, cm	19	1	16	21	17	31	19	16	16	16
E_{max}, kV/cm	250	–	200	–	200	–	250	170	–	170
Synchronous phase	$\pi/2$	–	45π	–	$\pi/4$	–	$\pi/5$	$\pi/5$	–	$\pi/5$
Aperture, cm	5	5	5	5	5	5	5	5	5	5

This scheme allows one to decrease bunch phase width in four times.

The computer simulation results are presented in Figures 10-13. Note, that transversal phase spaces are the same that in the first scheme.

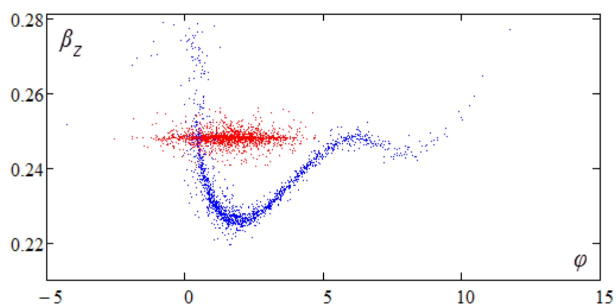

Figure 10: Longitudinal phase space.

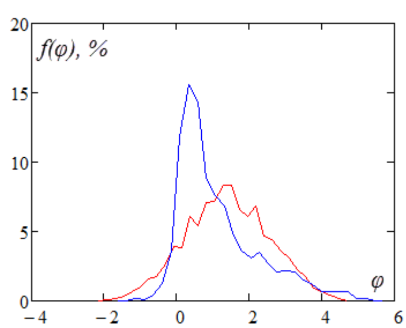

Figure 11: Particle distribution by phases.

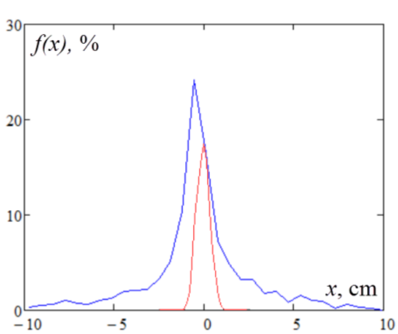

Figure 12: Particle distribution by the first transversal coordinate.

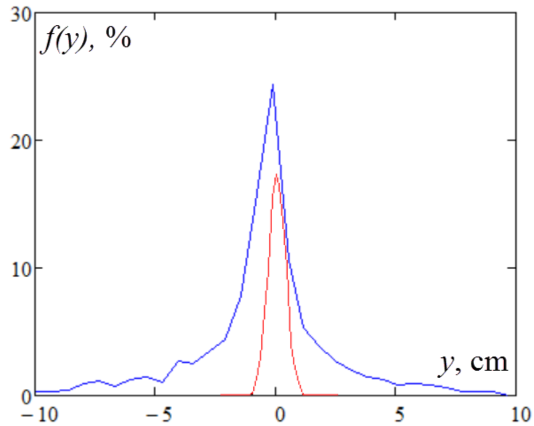

Figure 13: Particle distribution by the second transversal coordinate.

It was obtained that transmission coefficient is equal to 74%.

CONCLUSION

It is proposed to use the system of independently phased bunchers for beam matching between cyclotron and linac for CYCLINAC concept. The BEAMDULAC-CYCLINAC program is developed for simulation of the self-consistent dynamics of proton beams in a matching channel. Results of the beam dynamics simulation are presented.

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