BEAM TRANSFER FROM HEAVY-ION LINEAR ACCELERATOR HILAC INTO BOOSTER OF NICA ACCELERATOR COMPLEX

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Abstract

Designs of systems of ion beam transfer from the linear accelerator HILAC into the Booster of the NICA accelerator complex (JINR, Dubna) [1] including the transport beam line HILAC-Booster and the beam injection system of the Booster are considered in the report. The proposed systems provide multi-variant injection for accumulation of beams in the Booster with required intensity. Special attention is paid to various aspects of beam dynamics during its transfer. Main methods of beam injection into the Booster are described. These are single-turn, multi-turn and multiple injection ones. Results of beam dynamics simulations are presented. Status of technical design and manufacturing of the systems' equipment is also highlighted.

INTRODUCTION

The systems of beam transfer from the HILAC linear accelerator to the Booster include the HILAC-Booster beam transport channel and the system of beam injection into the Booster (see Figure 1).

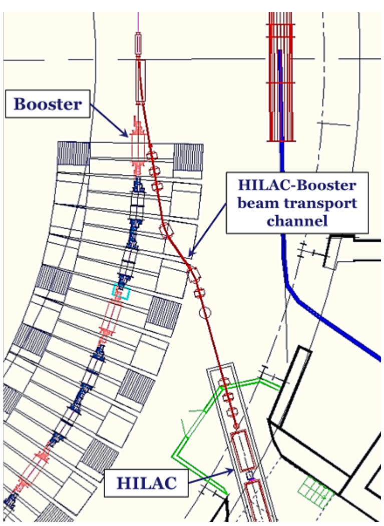

Figure 1: Layout of the HILAC linear accelerator, the Booster synchrotron and the HILAC-Booster beam transport channel.

The beam transfer in the HILAC-Booster transport channel involves beam debunching, betatron matching of ion beam of the target charge state with the Booster, separation and collimation of neighbor parasitic charge states of ions. The ion-optical system of the transport channel and the beam injection system of the Booster provide multi-variant injection for accumulation of beams in the Booster with required intensity [2]. Main methods of beam injection into the Booster are single-turn, multi-turn and multiple injections. Ions (see Table 1) are accumulated on the horizontal phase plane of the Booster.

Table 1: Main Beam Parameters

Ions	Au^{30+}, Au^{31+}, Au^{32+} (from HILAC); Au^{31+} (inside Booster)
Intensity	up to $2.5\cdot10^9$ (Au^{31+}); up to $6\cdot10^9$ (total)
Current, mA	4
Energy, MeV/amu	3.2
Repetition rate of beam injection into Booster, Hz	0.25
Repetition rate of stages of multiple injection, Hz	10 (3 injection stages per 4 s)
Transition, %	90
Transverse 95% emittance, $\pi\cdot$mm$\cdot$mrad:	
at the exit of HILAC;	10
at the entry of Booster;	15
after filamentation in Booster.	15 ÷ 135 (hor.) / 15 (vert.)

BEAM INJECTION INTO BOOSTER

Concept of multi-variant injection into the Booster synchrotron implies possibility of beam injection by means of several schemes of single-turn, multi-turn and multiple injection methods. The beam injection system of the Booster is designed to create a local closed orbit bump and also has useful feature: ability of rapid change of fields inside the system's kickers that allows ions to fill the horizontal phase plane of the Booster more compact.

Single-turn injection is a conventional method providing minimal transverse beam emittances after filamentation of phase space distribution of ions in the Booster. The beam duration in case of single-turn injection is less than 8.5 µs. Horizontal emittance of the injected beam is equal to 15 $\pi\cdot$mm$\cdot$mrad. Vertical emittance does not depend on beam injection method used and is 15 $\pi\cdot$mm$\cdot$mrad.

Multi-turn injection method involves accumulation of ions on the horizontal phase plane during 2-3 periods of the beam revolution so the beam duration is 17 or 25.5 µs. Two schemes of multi-turn injection are considered: with single-plateau (ordinary) pulses of the injection system's kickers and with double-plateau pulses formed by rapid change of fields in the kickers. Horizontal emittances of

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the accumulated beam after filamentation in the Booster according to these beam injection schemes are 120 π·mm·mrad and 65 π·mm·mrad correspondingly.

Multiple injection method means twice or triple repetitions of single-turn beam injections (or stages of multiple injection) with periodicity of 100 ms. Modes of single-plateau and double-plateau pulses of the kickers are also used for multiple injection. Additional option is variation of the horizontal phase portrait of the injecting beam (provided by dynamic retuning of the HILAC-Booster beam transport channel in intervals between stages of multiple injection) which allows more compact filling of the phase plane. There are six schemes proposed for multiple injection which give horizontal emittances of the accumulated beam after filamentation in the Booster in the range from 55 π·mm·mrad to 135 π·mm·mrad.

BEAM INJECTION SYSTEM

The beam injection system of the Booster consists of the electrostatic septum IES and the electric kickers IK1 – IK3. The kickers serve to put the beam onto the closed orbit of the Booster (in case of single-turn injection) and to create a local bump of the closed orbit (in cases of multi-turn and multiple injection schemes).

The system's elements are located in the vicinity of the 1st straight section of the Booster (see Figure 2). The kickers IK1 and IK3 are placed inside the Booster cryostat in periodic DFO cells adjacent to the 1st straight section. The electrostatic septum IES and the kicker IK2 are positioned in the 1st straight section itself. The section has a bypass of cryogenic and superconducting communications and the largest part of the section including the septum and the kicker is room-temperature.

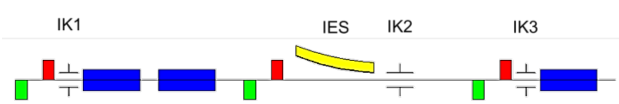

Figure 2: Layout of the beam injection system of the Booster. Notation: blue – lattice dipole magnets, red – focusing quadrupole lenses, green - defocusing quadrupole lenses.

The electrostatic septum IES (see Figure 3) is a pair of curved electrodes installed inside a vacuum box. The cathode is positioned on the outside of the anode. High voltage is applied to the cathode, the anode is grounded. Length of the IES is 1.9 m. Gap between the electrodes is 35 mm, thickness of the anode (which serves as a knife of the septum) is 1 mm.

The IES is operated in the cyclic mode. A constant voltage between the septum electrodes is maintained during the beam injection. There is capability to vary the voltage in intervals between stages of multiple injection. The range of the voltage variation is from 116 kV up to 125 kV.

Currently the technical design of the electrostatic septum IES is finished and its manufacturing will be started in the nearest future.

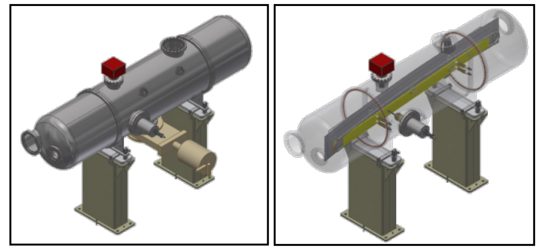

Figure 3: 3D model of the electrostatic septum IES.

The electric kickers IK1 – IK3 (see Figure 4) are pairs of conducting plates installed vertically inside vacuum boxes parallel to the Booster axis. Lengths of the kickers IK1 and IK3 are 0.45 m, length of the IK2 is 0.8 m. The plates of the kickers IK1 and IK3 are positioned symmetrically relative to the Booster axis and gaps between the plates are 102 mm. The plates of the kicker IK2 are shifted outside the Booster axis, the gap is 93 mm.

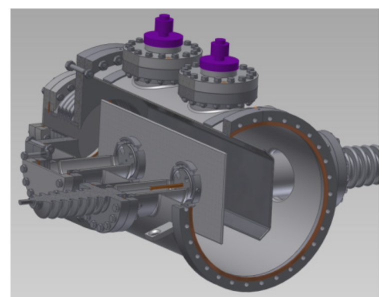

Figure 4: 3D model of the electric kicker IK1.

Five power supplies of the kickers [3] provide independent unipolar charging/discharging of each of the plates (excluding one of the plates of the kicker IK1). Two modes of the kickers' operation are considered. The single-plateau pulse mode means that electric potential is applied only on one plate of the kicker (the primary plate). In case of the double-plateau pulse mode, potentials are initially applied on both plates of the kicker then one of the plates (the secondary one) is discharged that leads to rapid change of voltage in the kicker.

Maximal voltage between the plates: IK1 – 40 kV, IK2 – 45 kV, IK3 – 60 kV. The power supplies are divided conventionally on high-voltage (up to 60 kV) ones feeding the primary plates and middle-voltage (up to 20 kV) ones feeding the secondary plates.

The kickers' pulses have a flat-top from 8 to 30 μs. The rise time of the pulse is about 1 ms, the fall time does not exceed 100 ns. Repetition rate of pulses in case of multiple injection is equal to 10 Hz, maximal number of repetitions is 3.

Currently the kicker prototype and the power supply (with voltage up to 60 kV) for its primary plate are almost manufactured and will be tested in the nearest months.

HILAC-BOOSTER BEAM TRANSPORT CHANNEL

Layout of the HILAC-Booster beam transport channel is shown in Figure 1. The beam transport channel provides the beam transfer only in the horizontal plane as the

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HILAC axis is located on the median plane of the Booster.

The beam transport channel contains 2 dipole magnets, 7 quadrupole lenses, a debuncher and a set of steerers. At present all the transport channel elements (see Table 2) are available at JINR.

Table 2: Main parameters of the magnets and the debuncher of the HILAC-Booster beam transport channel.

Dipole magnets	
Effective length, m	0.65
Max. magnetic field, T	1
Gap, mm	45
Quadrupole lenses	
Effective length, m	0.29
Max. gradient, T/m	10
Gap (diameter), mm	95
Debuncher	
Length, m	0.49
Frequency, MHz	100.625
Max. effective voltage, kV	260

The beam transport channel has the following functionality: the beam matching with the Booster ring, the beam debunching, separation of neighbor parasitic charge states of ions, capability to modify position and Twiss parameters of the transferring beam at the exit of the channel (to provide different schemes of the beam injection into the Booster).

The debuncher provides reduction of longitudinal momentum spread of the beam from initial value of $5\cdot10^{-3}$ (at the exit of the HILAC) to $1\div1.5\cdot10^{-3}$ (the upper value is a semi-height of the Booster separatrix). To increase efficiency of the debuncher operation it is installed at the end of the 1st straight section of the beam transport channel in the non-dispersive region.

Separation of charge states of ions is fulfilled by means of the 1st dipole magnet. Separated parasitic charge states of ions (Au^{30+} and Au^{32+} for case of Au^{31+} target ions) are collimated just before the entrance of the second dipole magnet.

The steerers distributed along the channel provide the beam trajectory correction. Full correction of the trajectory (i.e. its alignment with the channel axis) is achieved inside the debuncher and in the end of the channel.

The special steerer is placed just after the final quadrupole lens. It is used for alteration of the beam position at the entry of the electrostatic septum IES which is required to perform several schemes of the beam injection into the Booster.

The vacuum chamber of the beam transport channel (except the dipole magnets) is considered to be round with radius of 35 mm. The vacuum chamber inside the dipoles is elliptical with semi-axes of 35 mm and 20 mm. Acceptance-limiting places of the channel are the collimators for parasitic charge states of ions and the vacuum chamber of the defocusing lens in the 1st triplet for horizontal and vertical acceptances accordingly (see Figure 5). Horizontal and vertical acceptances of the channel are close to each other and equal to 28 π·mm·mrad and 30 π·mm·mrad correspondingly.

Growth of effective transverse emittances of the beam in the transport channel is limited by 50%. The beam dynamics simulations have shown that the emittance growth due to the debunching and chromatic effects is perceptible but does not exceed 15% and 25% for horizontal and vertical effective emittances accordingly. Other sources of the emittance growth such as errors and space charge effects also do not lead to violation of the emittance budget.

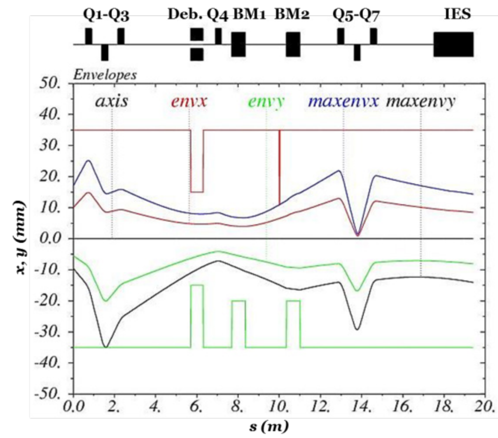

Figure 5: The beam envelopes in the HILAC-Booster beam transport channel and the electrostatic septum IES. Positive values on axis *x,y* mean horizontal coordinates, negative ones represent vertical coordinates. Notation: BM1-BM2 – dipole magnets; Q1-Q7 – quadrupole lenses; Deb. – debuncher; *envx*, *envy* – horizontal and vertical envelopes of the beam with transverse emittances equal to 10 π·mm·mrad; *maxenvx*, *maxenvy* – horizontal and vertical envelopes of the beam with transverse emittances equal to the channel acceptances.

CONCLUSION

Concept of multivariant beam injection into the Booster has been proposed. The systems of the beam transfer from the HILAC to the Booster have been developed such a way all the considered schemes of the beam injection are capable to be implemented. Technical designs of the systems' devices are near to completion and some devices are being fabricated to date.

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