FORMATION OF BEAMS IN THE ION ACCELERATOR COMPLEX OF THE MEDIUM ENERGY ELECTRON ION COLLIDER FACILITY AT JLAB*

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Abstract

At the interaction point of the Medium Energy Electron Ion Collider (MEIC) facility the luminosity of $10^{33}\text{cm}^{-2}\text{s}^{-1}$ will be achieved through the collision of counter rotating beams of 0.5A ions and 3A electrons at 750MHz frequency. Formation of ion beams at MEIC is carried out in the Ion Accelerator Complex (IAC) comprising of a linac, pre-booster ring, booster ring, and a collider ring [1]. We will describe the scheme proposed for the formation of ion beams at MEIC facility from the point of view of longitudinal beam dynamics. The proposed scheme minimizes losses due to space charge effects at low energies and needs moderate RF requirements already achieved at other existing facilities. Simulation studies have been conducted to verify the proposed scheme. We will present the results of these simulation studies.

MEIC ION ACCELERATOR COMPLEX

The Ion Accelerator Complex (IAC) is comprised of ion sources, ion linac, pre-booster ring, booster ring, and a medium energy collider ring. Formation of beam along the chain has been studied and verified using computer simulations. The exact scheme for formation of beam will depend on the ion species. We choose protons and lead ions as representative cases for light and heavy ions. In order to achieve the final design beam parameters for medium energy collider ring, the ions go through several phases of acceleration, accumulation, de-bunching and re-bunching in the IAC. The evolution of the beam parameters along the chain is summarized in Table 1 for protons and Table 2 for lead ions respectively. Below we describe the scheme and present simulation results to verify key steps in the scheme.

Accumulation of Ion beams

In the MEIC ion complex, accumulation of ion beams takes place in the pre-booster synchrotron, combined with stripping of additional electrons from ions in the linac and pre-booster. Process is slightly different for protons and lead ions as described below.

Proton beam micro bunch structure of pulses in the linac comprises of 25300 micro bunches in a 115 MHz repetition rate and are combined into a pulse of 0.22 ms long. Such pulse will fill up the pre-booster with 10^{12} protons. The proton bunch at the end of the acceleration ramp in the pre-booster is extracted to the large booster by a bunch to bucket transfer method. We assume that the large booster will operate with harmonic number 5, and hence five such transfers will be performed in a time period of around 0.8 s

Lead ion beam accumulation would very much follow that of a proton beam, the only difference is in the beginning part of acceleration cycle. With the present state-of-the-art source technologies, a pulse current up to 0.5 mA over a 0.25 ms time duration for lead ions could be expected from the heavy ion sources but the pulse repetition rate could be relatively high, up to 10 Hz. Taking into account the particle loses during stripping in the ion linac, one fill-up of the pre-booster to the required intensity will need 28 pulses of such linac beam. This pre-booster fill-up and stacking is performed with help of repeated multi-turn painting injection or/and electron cooling. Since the cooling time for the contemplated beam parameters is shorter than time between the pulses of the maximum anticipated repetition rate, it is estimated that this process will take approximately 2.8 s. As discussed below, acceleration of lead ions in pre-booster can be done in about 0.144 s, this leads to approximately 3.1 s cycle time in the pre-booster cycle times of 3.1 s. Finally, we could conclude that the large booster can be filled in about 15.5 s.

Acceleration of Ion Beams

In pre-booster the proton or lead pulse, once painting-injected into the pre-booster, becomes a coasting beam. It will be RF captured and accelerated on the first harmonic utilizing LEIR-type FINEMET cavities [2] that can cover the full frequency range required to accelerate protons to lead ions in the pre-booster, up to the third harmonic, with parameters listed in Table 3. As an example we show the longitudinal phase space particle distributions at the beginning, middle and end of the acceleration ramp for protons in Fig. 1. Acceleration is achieved according to the voltage-synchronous-phase curves shown in Fig. 2.

Space charge is obviously a limiting effect in the pre-booster. Here we assumed ratio of beam intensities in the large booster and pre-booster is 5, close to the ratio of

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Table 1: Evolution of Polarized Proton Beam Current in MEIC Ion Complex

		Source	**Linac**	**Pre-booster**		**Large Booster**	**Collider Ring**
		ABPIS	At exit	At Injection	After boost	After boost	After boost
Charge status		H^-	H^-	H^+	H^+	H^+	H^+
Kinetic energy	MeV/u	~0	13.2	285	3000	20000	60000
γ and β				1.3 / 0.64	4.2 / 0.97	22.3 / 1	64.9 / 1
Pulse current	mA	2	2	2			
Pulse length	ms	0.5	0.5	0.22			
Charge per pulse	μC	1	1	0.44			
Ions per pulse	10^{12}	3.05	3.05	2.75			
Pulses				1			
Efficiency				0.9			
Total stored ions	10^{12}			2.52	2.52	2.52x 5	2.52x5
Stored current	A			0.33	0.5	0.5	0.5

Table 2: Evolution of Polarized Lead Beam Current in MEIC Ion Complex

		Source	**Linac**	**Pre-booster**		**Large booster**		**Collider ring**
		ECR	After stripper	At injection	After boost	before injection	After Boost	After boost
Charge status		$^{208}Pb^{30+}$	$^{208}Pb^{67+}$			$^{208}Pb^{82+}$		
Kinetic energy	MeV/u	~0	13.2	100	670	670	7885	23653
γ and β				1.11 / 0.43	1.71 / 0.81	1.71 / 0.81	9.4 / 0.99	26.2 / 1
Pulse current	mA	.5	0.1					
Pulse length	ms	0.25	0.25					
Charge per pulse	μC	0.125	0.025					
Ions per pulse	10^{10}	1.664	0.332					
Number of pulses				28				
Efficiency			0.2	0.7		0.75		
Total ions	10^{10}			4.5		3.375x5		
Stored current	A			0.26	0.5	0.447	0.54	0.54

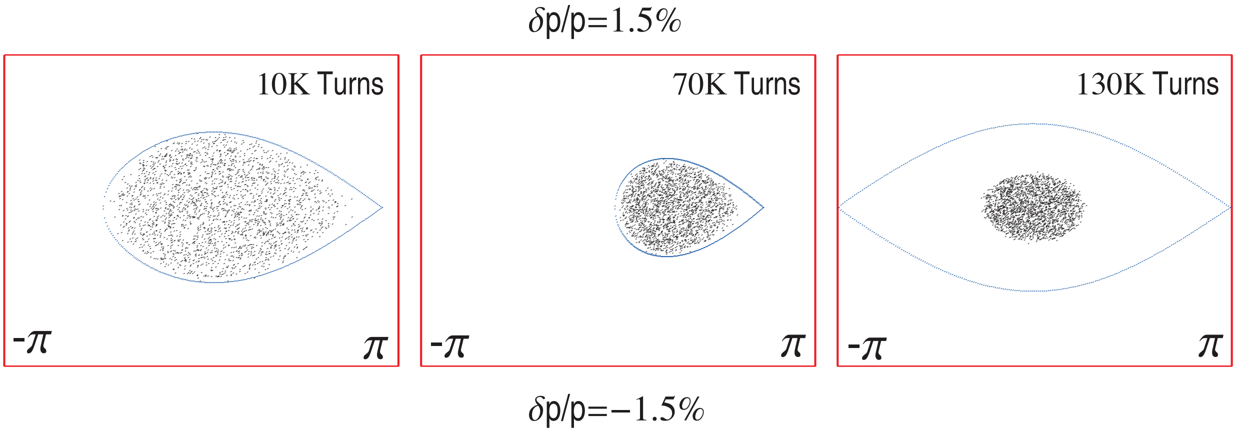

Figure 1: COSY Infinity [3] simulation of longitudinal dynamics for proton beams in the MEIC pre-booster at the beginning, middle and end of the acceleration ramp.

circumferences. In case the space charge in the pre-booster is too strong thus mitigation is required, there are two options: controlled emittance blow-up in the pre-booster and/or further beam accumulation (beyond the factor 5 assumed) in the large booster. Assuming acceleration parameters in Table 3 and a kicker rise/fall time of approximately 100 ns, the maximum harmonic number possible in the large booster is 24 for protons and 10 for lead ions. Therefore, accumulation in the large booster with h=10 would allow a reduction of the required intensities in the pre-booster by a factor of two, appropriately reducing the space charge effects. In addition, mitigation of space charge effects would also allow reduction of final energy of the ion linac, i.e., cost savings.

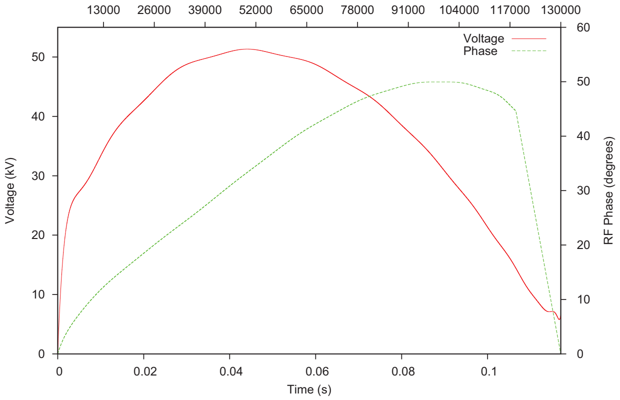

Figure 2: Voltage-synchronous-phase curves for protons.

Table 3: Pre-booster Parameters

	Units	Proton	Lead
Initial & final kinetic energy	MeV/u	285 / 3000	100 / 670
Initial momentum spread	%	±0.3	±0.054
Initial beam emittance (RMS)	eV·s	0.295	6.48
RF harmonic number		1	1
RF frequency	MHz	[0.82,1.25]	[0.55,1.04]
Maximum RF voltage	kV	51.2	48.8
Maximum phase	deg	50	50
Momentum compaction		0.039	0.039
Final capture efficiency factor		0.999	0.95
Final momentum spread	%	±0.27	±0.11
Final Beam emittance (RMS)	eV·s	0.19	8.00
Total turns	1000	130	115
Acceleration period	ms	117	144
Bunch length	Ms	0.166	0.386

In large booster to accelerate beams we will use voltage-phase curves appropriately scaled from the pre-booster case. The preliminary parameters for accelerating proton beam are listed in Table 4 assuming a small positive momentum compaction.

Table 4: Accumulation and Acceleration Parameters for Protons in Large Booster Ring

Initial & final kinetic energy	GeV/u	3 & 20
Assumed momentum compaction		0.039
Accumulation stage		
Initial momentum spread	%	±0.27
Initial beam emittance (RMS)	eV·s	0.19
RF harmonic number		5
RF frequency	MHz	1.21
Maximum RF voltage	kV	15
Final capture efficiency factor		1
Total turns		194172
Accumulation time	s	0.8
Minimum bunch separation	µs	0.25
Maximum bunch separation	µs	0.48
Acceleration stage		
RF harmonic number		5
RF frequency	MHz	[1.21,1.24]
Maximum RF voltage	kV	208
Final capture efficiency factor		1
Final momentum spread	%	±0.4
Final Beam emittance (RMS)	eV·s	0.38
Total turns		200000
Acceleration period	ms	806
Average bunch separation	µs	0.71

In collider ring the beam transported from the large booster ring still has a 1.24 MHz bunch structure from the large booster accelerating RF. However, this beam needs to be redistributed evenly into 750 MHz buckets in the collider ring for acceleration and collisions. This is achieved by debunch/rebunch of the beam. Initial studies show that the proton beam debunching time is about 4 s or 0.99 million turns. The total time from source to start of re-bunching to high frequency for collisions in the collider ring will take approximately 6s in the case of proton beams.

SUMMARY

We have described a scheme for formation of ion beams at MEIC and presented simulation results to verify key steps in the accumulation and acceleration of ion beams. All these factors will be the subjects of future beam dynamics studies and cost optimizations.

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