PULSED SC ION LINAC AS AN INJECTOR TO BOOSTER OF ELECTRON ION COLLIDER*

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Abstract

The medium energy electron-ion collider (MEIC) being developed at JLAB requires a new ion accelerator complex (IAC). The IAC includes a new linac and a new booster accelerator. The new facility is required for the acceleration of ions from protons to lead for colliding beam experiments with electrons in the EIC storage ring. Originally, we proposed a pulsed linac with a NC front-end up to 5 MeV/u and a SC section for higher energies. The linac is capable of providing 285 MeV protons and ~100 MeV/u lead ions for injection into the IAC booster. A recent cost optimization study of the IAC suggested that lower injection energy into the booster may reduce the overall cost of the project with ~130 MeV protons and ~42 MeV/u lead ions. Stronger space charge effects in the booster caused by lower injection energy will be mitigated by the appropriate booster design. In this paper we discuss both linac options.

INTRODUCTION

Several years ago we developed a multi-ion injector linac design for the medium energy EIC (MEIC) capable of providing ~285 MeV protons and ~100 MeV/u lead ions [1,2]. This linac consisted of 122 superconducting (SC) cavities housed in 16 cryomodules. Recently, significant progress has been made at ANL with the developments of high-performance quarter-wave resonators (QWRs) and half-wave resonators (HWRs). Particularly, both QWRs and HWRs can provide very high accelerating gradients by operating at peak electric and magnetic fields up to 60 MV/m and 90 mT respectively. If we apply this technology to the design of a pulsed multi-ion linac, the cavity and cryomodule count can be notably reduced. In addition, by lowering the injection energy of lead ions to ~42 MeV/u and implementing newly developed technologies, the cost of the multi-ion superconducting linac may be reduced by nearly a factor of 3 relative to the current proposed 100 MeV/u linac option. The cost reduction is driven by the reduced number of SC cavities and cryomodules.

HEAVY-ION LINAC PARAMETERS

A block-diagram of the new linac is shown in Figure 1 and the basic design parameters are listed in Table 1. The economic acceleration of lead ions to 42 MeV/u requires

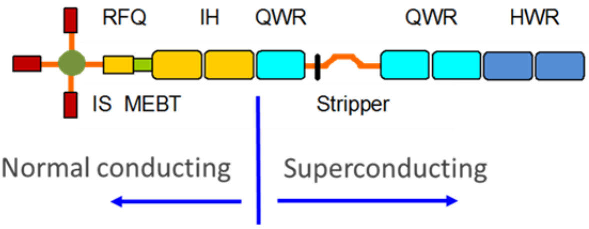

Figure 1: A schematic drawing of the MEIC ion linac.

Table 1: Main Parameters of the Linac

Parameter	Units	Value
Ion species		H^+ to Pb
Fundamental frequency	MHz	100
Kinetic energy of protons & lead ions	MeV/u	130&42
Maximum pulse current		
Light ions (A/q≤3)	mA	2
Heavy ions (A/q>3)	mA	0.5
Pulse repetition rate	Hz	up to 10
Pulse length		
Light ions (A/q≤3)	ms	0.5
Heavy ions (A/q>3)	ms	0.25
Maximum pulsed beam power	kW	260
# of QWR cryomodules		3
# of HWR cryomodules		2
Total length	m	~55

a stripper in the linac with an optimum stripping energy of ~8.2 MeV/u, obtained from the plot of total accelerating voltage as a function of the stripping energy shown in Figure 2. The stripping efficiency of lead ions to the most abundant charge state 61+ is 17.5%.

The MEIC ion linac will use several ion sources (IS)

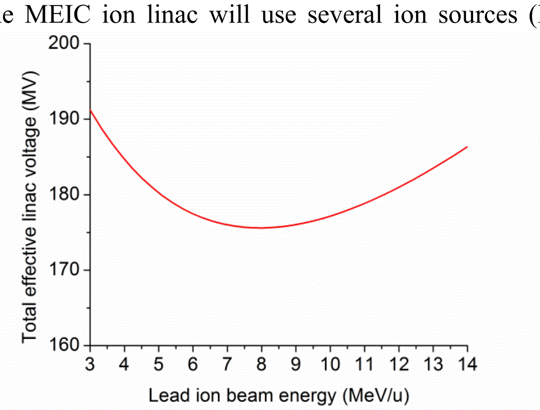

Figure 2: Total effective linac voltage as a function of the stripping energy of lead ions.

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including a polarized light ion source. The beam is injected into a room temperature radio-frequency quadrupole (RFQ) followed by an IH structure operating at a fixed velocity profile, similar to the CERN lead-ion linac [3] and to the BNL pulsed heavy-ion injector [4]. We have selected 100 MHz as the fundamental frequency for the RFQ and the first section of the IH structure. The last 2 sections of the IH structure can be operated at 200 MHz to provide higher shunt impedance following the example of the CERN lead-ion linac. The normal conducting section provides 4.8 MeV/u energy for all ions, and is considered highly cost-effective, especially for pulsed machines. The ion beams will be subsequently accelerated by the SRF section of the linac which comprises two different types of accelerating cavities to cover the velocity range from 0.1c to 0.4c where c is the speed of light. The QWRs and HWRs operating at 100 MHz and 200 MHz respectively are similar to those that have been developed recently at ANL for the ATLAS upgrade and application in the FNAL proton driver. Photos of the QWR and HWR resonators developed and successfully operated at ANL are shown in Figure 3 and 4. Based on our experience, we propose to operate the MEIC linac at peak surface fields up to ~90 mT and ~60 MV/m. In the low-duty cycle pulsed operating regime, these fields can be readily achieved and maintained in operation without notable X-ray radiation. Due to the operation in pulsed mode, the dynamic heat load is negligible and the operation is proposed at 4.5K. The SC cavities will be combined into ~5.5 m long cryostats together with SC focusing solenoids. Due to the vast experience at ANL, no significant design work will be required to develop and build these cavities and cryomodules. The MEIC ion linac comprises 35 SC cavities housed in 5 cryomodules, with the RF parameters listed in Table 2. The cavity parameters were approximated from previously built QWRs and HWRs and refined with MWS simulations. A dog-leg magnet system is foreseen after the stripping foil to dump unwanted charge states in a designated area. The linac can be re-phased to accelerate any ion from proton (H^-) to lead. Though this linac was originally designed to provide optimal voltage gain for lead ions, due to the wide velocity acceptance of the proposed cavities, lighter ions can be accelerated to higher velocities. Figure 5 shows the cavity effective voltage for lead ions and protons as a function of beam energy.

Figure 3: 72.75 MHz quarter wave resonator.

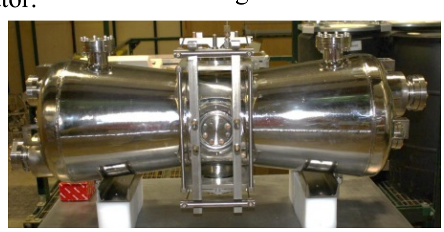

Figure 4: 162.5 MHz half wave resonator.

It is worth noting that all the technical systems of this linac are based on well-developed technologies and some of them are commercially available. The phase space parameters of the ion beam at the exit of the linac are as follows: 1 π·mm·mrad transverse normalized emittance, 10 π·keV/u·nsec longitudinal emittance and 0.1% momentum spread.

Table 2: Design Parameters of SRF Resonators for MEIC Ion Linac

Parameter	Units	QWR	HWR
β_{OPT}		0.15	0.30
f	MHz	100	200
Length (βλ)	cm	45	45
E_{PEAK}/E_{ACC}		5.5	4.9
B_{PEAK}/E_{ACC}	mT/(MV/m)	8.2	6.9
R/Q	Ω	475	256
G	Ω	42	84
E_{PEAK}	MV/m	57.8	51.5
B_{PEAK}	mT	86.1	72.5
E_{ACC}	MV/m	10.5	10.5
Phase	deg	20	30
Number of cavities		21	14

PULSED OPERATION CONSIDERATIONS

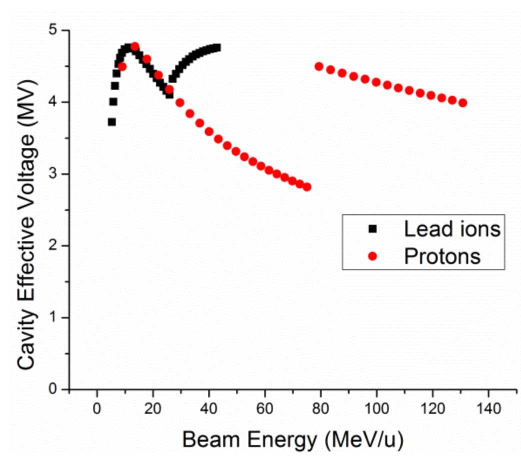

Figure 5: Cavity effective voltage as a function of beam energy.

The phase-locked pulsed operation of SC cavities requires proper control of the dynamic microphonic and Lorentz detuning. Cavities similar to those proposed for the MEIC have been developed at Argonne National

Laboratory for continuous wave operation [5, 6]. The total detuning in the pulsed mode of operation can be extrapolated from ANL's experience with QWRs and HWRs. Particularly, this experience suggests that the steady-state microphonic detuning of QWRs and HWRs for the MEIC injector will be about 40 Hz and 50 Hz respectively. While the Lorentz detuning is expected to be at the level of ~100 Hz for the QWRs and ~75 Hz for the HWRs. The Lorentz detuning can be partially compensated by offsetting the cavity operating frequency. Phase locked operation of the cavity can be controlled by a Low Level RF system by switching between self-excited and driven modes of operation during each RF pulse [7]. The driven mode is applied for the beam acceleration during the RF pulse flat top.

The microphonic detuning of the cavities can be controlled either by additional RF power or a fast piezoelectric tuner. These type of tuners have been developed successfully for the pulsed operation of elliptical-cell and spoke-loaded cavities [8,9] and are capable of compensating both microphonic and dynamic Lorentz detuning.

In the MEIC linac, the minimum required RF power is defined by the acceleration of light ions, particularly H^- beam. Figure 6 shows the required RF power for QWRs as a function of the external Q-factor for two cases: (a) the microphonic detuning is controlled by piezotuners and (b) by overcoupling to provide a tuning window of 40 Hz.

Figure 6 demonstrates that the required RF power is doubled by the microphonic detuning compared to the RF

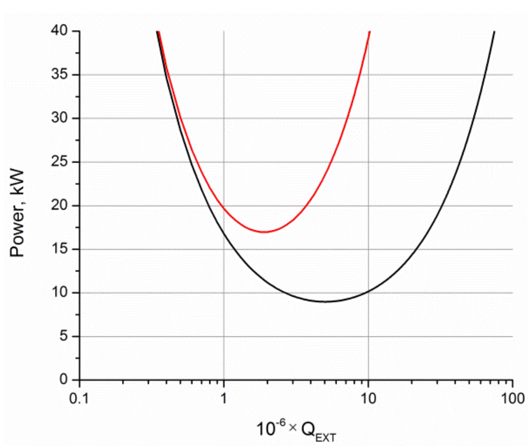

Figure 6: Required RF power for the QWR as a function of the external Q-factor when the microphonic detuning is controlled by piezotuners (black) and by additional RF power (red).

power required for beam loading only. The RF duty cycle in the EIC linac will be ~10%. The pulsed solid state RF amplifiers are less expensive than CW amplifiers. Therefore controlling microphonic detuning with an additional RF power can be comparable with the piezotuner option in terms of the cost.

In the stage of the conceptual design of the EIC accelerator complex, it is reasonable to consider both options to control cavity microphonic detuning. Figure 7 shows a concept of pizeotuners for QWRs and HWRs under preliminary investigation at Argonne. Future work will encompass characterizing this tuner for the compensation of both microphonic and dynamic Lorentz detuning.

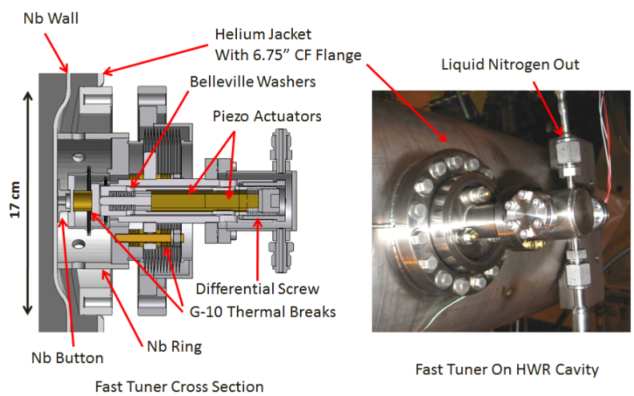

Figure 7: Fast piezo-electric tuner example for QWRs and HWRs.

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