RIA POST ACCELERATOR DESIGN

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Abstract

Overall design of the post accelerator for the RIA project is described with emphasis on performance for different ion beams. Characteristics for beams from A=10 to A=240 are provided with an estimate of output intensities. The selection rational for different accelerating structures, both for the normal conducting and for the superconducting types, is provided for a system design that accelerates beams to at least 10 MeV/u for heavy ions and up to 20 MeV/u for light ions.

INTRODUCTION

The RIA post accelerator design is based on significant developments for planned and operating facilities in Japan, Europe and North America: ANL [1-3], TRIUMF [4-5], MSU [6-8] and Frankfurt [9]. The post accelerator provides ion beams of 10 MeV/u for masses up to A=240 and up to 20 MeV/u for light masses (A<80). See Table 1 for values of the general parameter and Fig. 1 for a block diagram of the post accelerator. Component frequencies are based on multiples of the initial 80.5 MHz driver linac frequency, a sub-multiple of the main 805 MHz used for most of the driver linac. The following text uses rounded numbers for system frequencies, (i.e. 10, 20, 40 and 80).

ROOM TEMPERATURE STRUCTURES

An isobaric separator that selects a single ion of interest transports ions from a 60 kV source to a post accelerator; unwanted ions stop in appropriate beam dumps. Singly charged ions from the isobaric separator with masses from A=240 down to A=10 have an unnormalized emittance of 30πmm.mrad for 95% of the 60 kV beam. Important post accelerator characteristics are large acceptance, adequate beam intensity within an acceptable transverse emittance for the accelerated isobars, good energy resolution for the output beam and good timing structure associated with good longitudinal emittance. An independent 60 kV ECR source feeds singly charged ions to the post accelerator for tuning and commissioning purposes, without passing beam through the isobaric separator.

A three-frequency (3-f) buncher prior to the RFQ aids in multiple species operation while shortening the RFQ length. In agreement with TRIUMF experience, we found that a 3-f performs as well as a 4-f concept, and with less complexity and less tuning/operation controls. Operation is best when the 10/20/30 MHz bunchers have rf field amplitudes respectively in kV 2.0/-1.0/0.66.

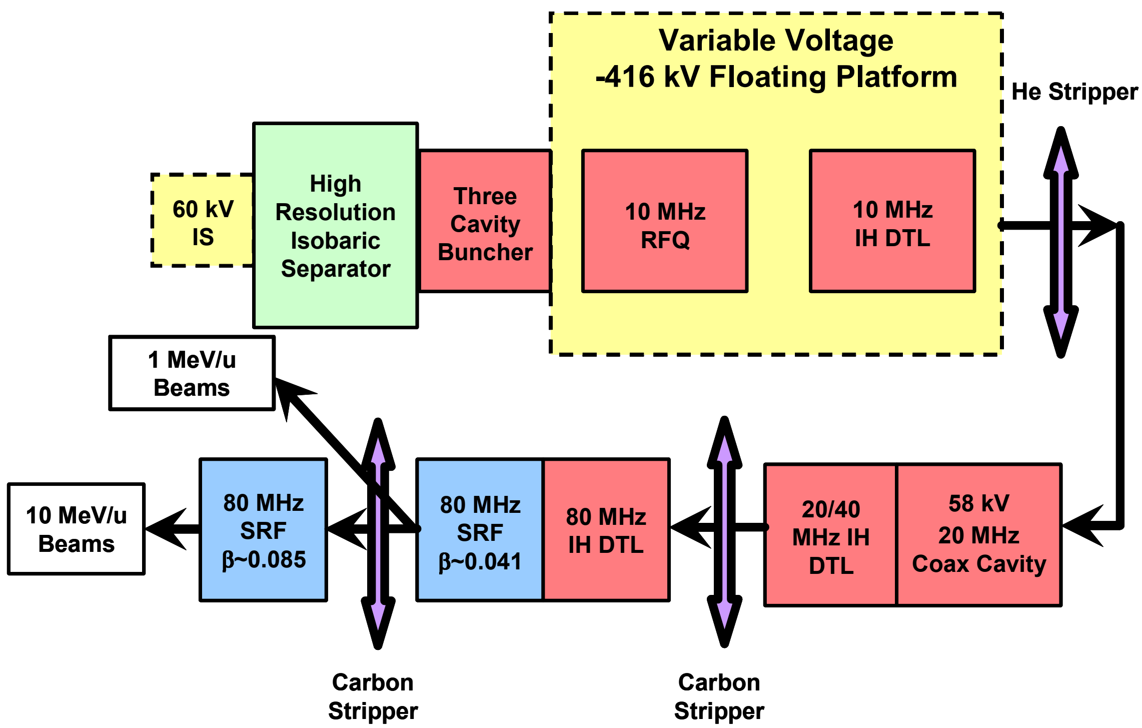

Figure 1: Schematic layout of the post accelerator showing components and the two beam extraction regions.

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Table 1: General Parameters for components of the post accelerator

Component	Frequency (MHz)	q/A Minimum	β In	β Out	Item or Cavity Number	Voltage (MV) for A=240
Ion Source	DC	1/240	--	0.0008	1	0.06
Isobaric Separator	DC	1/240	--	--	1	--
Three Cavity Buncher	10, 20, 30	1/240	0.0008	0.0008	3	--
RFQ*	10	1/240	0.0021	0.0041	1	1.4
IH DTL*	10	1/240	0.0041	0.0066	1	2.9
He Stripper (A>40)	--	1/66	0.0063	0.0063	1	--
Coax Cavity	20	1/66	0.0063	0.0063	1	0.058 Max
IH DTL	20/40	1/66	0.0063	0.015	1	5.2
C Stripper	--	1/16	0.015	0.015	1	--
IH DTL	80	1/16	0.015	0.024	1	2.6
β=0.038 SRF	80	1/16	0.024	0.047	34	12.2
C Stripper	--	1/7	0.047	0.047	1	--
β=0.08 SRF	80	1/7	0.047	0.129	48	45.0
β=0.08 SRF	80	1/7	0.129	0.146	16	13.7

* Components on variable high voltage platform: entering or leaving platform results in voltage change.

All cw room temperature structures operate with maximum surface fields less than 1.75 the Kilpatrick criterion to minimize micro-discharges and beam disruption. A four-rod RFQ and IH drift-tube linac (DTL) on a floating platform ensure good beam capture for ions from A=10 to A=240. To ensure ion velocities meet RFQ injection constraints, platform voltage varies for different mass ions. Platform maximum voltage was a compromise between operation within sound high-voltage practice and beam optics choices.

Beam dynamics calculations showed that the RFQ and the first IH DTL should be less than 15 MHz for efficient acceleration of the most demanding ion in terms of dynamics, 476 kV $^{240}U\ 1^+$ DC beam. Hence, 10 MHz and the frequency doubling scheme chosen to ensure good beam properties for all mass ions. For example, for an input normalized transverse emittance (ε_T=0.002 π cm.mrad) the 10 MHz design with 1 cm bore radius had ~100% capture versus only 21.9% for a 20 MHz design with 0.5 cm bore radius.

A reduction in rf accelerating fields by a maximum factor of 24 in the room-temperature structures matches ion velocities over the full mass range. Such an rf voltage range should not lead to multipactoring or field emission difficulties as long as structures are conditioned properly and design takes into account the rf voltage range.

Table 2: Performance for various ions when rf fields are controlled to give 10 MeV/u for all output ions.

A	10	20	40	65	84	131	184	197	240
Element	B	Ne	Ar	Zn	Kr	Xe	W	Au	U
From Platform (10 MHz RFQ + 10 MHz IH)									
Charge	1	1	1	1	1	1	1	1	1
A/q	10	20	40	65	84	131	184	197	240
Transmission Eff. %	90%	90%	90%	90%	90%	90%	90%	90%	90%
He Stripper									
Major states	1	1	1	2	2	3	3	3	4
A/q	10.0	20.0	40.0	32.5	42.0	43.7	61.3	65.7	60.0
Single Charge Stripping Eff. %	100%	100%	100%	47%	47%	38%	41%	40%	35%
20 MHz IH + 40 MHz IH + Doublet Quads Output									
MeV/u	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105
RF P Red.	36.00	9.00	2.25	3.41	2.04	1.89	0.96	0.83	1.00
C Stripper									
Major states	2	4	5, 6	8, 9	9, 10	11 - 13	11 - 13	12 - 14	14 - 16
A/q	5.0	5.0	6.7	8.1	9.3	10.9	15.3	15.2	16.0
Dq/q	-	-	17%	13%	11%	17%	17%	15%	13%
Transmission Eff. %	50%	40%	54%	44%	45%	55%	50%	49%	50%
80 MHz IH + Doublet Quads Output									
MeV/u	0.268	0.268	0.268	0.268	0.268	0.268	0.268	0.268	0.268
RF P Red.	10.24	10.24	5.76	3.88	2.94	2.15	1.09	1.11	1.00
80 MHz β = 0.038 SRF Output									
MeV/u	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03
RF P Red.	10.24	10.24	5.76	3.88	2.94	2.15	1.09	1.11	1.00
C Stripper									
Major states	2	4	11 - 13	16 - 19	17 - 20	25 - 29	30 - 34	31 - 35	35 - 39
A/q	5.0	5.0	3.3	3.6	4.4	4.9	5.8	6.0	6.5
Dq/q	-	-	17%	17%	16%	15%	13%	12%	11%
Transmission Eff. %	100%	100%	88%	78%	67%	86%	86%	73%	74%
80 MHz β = 0.08 SRF Output									
MeV/u	10.1	10.1	10.1	10.1	10.1	10.1	10.1	10.1	10.1
RF P Red.	1.68	1.68	3.79	3.23	2.15	1.79	1.27	1.18	1.00
Overall Transmission Eff. %	45%	36%	43%	15%	13%	16%	16%	13%	12%

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Simulations for the IH DTLs showed that best matching and beam characteristics result from using doublet quadrupoles rather than triplet quadrupoles between each of the four tanks comprising each IH DTL. The first IH DTL at 10 MHz is the only one of the four different frequency IH DTLs that is on the floating platform, for reasons of rf power simplification, beam dynamics and energy gain requirements. Cell number per tank varies from 6 to 9 for the 10 to 80 MHz structures respectively.

A simple coaxial-loaded cavity provides the rf voltage needed for proper injection to the 20 MHz IH DTL, because the voltage experienced in leaving the platform is different for the different ions. Because of these different platform voltages, no beam stripper should be on the platform. This choice ensures that the rf impulse from the coaxial cavity is as low as possible.

Strippers shown in Fig.1 were determined based on optimized performance, minimizing accelerator length, minimizing rf requirements and reasonable ion beam transmission. Ions with A>40 are stripped by a He stripper after the beam has left the high voltage platform at 18.3 keV/u ($\beta \sim 0.00626$) to 2+ to 4+ states depending on the ion mass as shown in Table 2. Efficiencies and charge states were determined from experimental data.

To utilize the 80 MHz quarter-wave SRF cavities developed for the driver linac, three room temperature IH DTL tanks (20, 40 and 80 MHz) increase the energy from the floating platform to 268 keV/u. Between the 40 and 80 MHz IH DTLs is a carbon stripper, as given in Table 2, increasing charge states for more efficient acceleration.

SUPERCONDUCTING STRUCTURES

Remaining portions of the post accelerator linac are all superconducting quarter wave structures operating at 80 MHz, similar to those developed at MSU. Thirty-four cavities of $\beta \sim 0.038$ quarter wave geometry take the beam to 1.03 MeV/u for A=240. At this point a carbon stripper is used to increase the charge state to include a combination of 35+ to 39+ for A=240 in order to have increased beam current for further acceleration in 80 quarter wave cavities of $\beta \sim 0.08$ geometry. Solenoid magnets are employed at the appropriate locations for beam focusing and to permit good operation with reasonable operating margins and low beam loss. A chicane scheme at each stripper location ensures removal of unwanted charge states.

Design of the superconducting section of the post accelerator is similar to that described in references 6-8. Much work is still needed to determine an optimum set of system parameters for best overall operation of the post accelerator covering the ion beam range of interest. Obviously one can obtain higher MeV/u for the lighter ions by making adjustments to the fields and phases for the quarter wave cavities, as well as for the transport elements. At least 20 MeV/u is possible for ions with A>80. Detailed beam dynamics studies will assist with parameter selection for the various components of the post accelerator and will help to determine tolerances and operating margins.

PERFORMANCE

Although Table 2 lists overall percentage transmission, anticipated yields in particle pA vary from 72.1, 57.7, 343, 23.3, 1630, 5180, 25.4, 20.6 to 18.7 for the ions listed from B to U respectively on the assumption that collection intensities from a 100 kW production target are 1, 1, 5, 10, 80, 200, 1, 1, to 1 in units of 10^9 particles per second for B to U respectively.

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