CONCEPTUAL DESIGN OF LINAC FOR POWER HIF DRIVER

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Abstract

Linac for singly-charged (positive and negative) ions of the four various Pt isotopes has been proposed. Eight beams of different charges and masses of ions are accelerated in parallel RFQ channels to an energy of 100 MeV. The beams are then brought together by a system of alternating gradient magnet for a $180°$ bending and matching of the beams. The main channel which accelerats all beams together consists of three stages. The first one (till 600 MeV) is a Wideroe structure followed by two consecutive Alvarez channels (2.5 GeV and 10 GeV) having different radio frequencies. Characteristics of the output beam for each kind of ions are: average pulse current 45 mA, horizontal emittance $0.6\pi \, cm \cdot mrad$, vertical emittance $0.4\pi \, cm \cdot mrad$, momentum spread $\pm0.07\%$, bunch length 3.6 cm, and spacing between bunches of each kind is 15.3 m.

Introduction

In this work we describe the scheme of a special linac (see Fig. 1) for simultaneous acceleration of eight platinum ions (four isotopes) till maximum energy of $10 \, GeV$. The total average pulse current is $8 \times 45 \, mA$. The linac is a beam generator for the power HIF driver with total stored energy $9.6 \, MJ$ and total power $\simeq 1000 \, TW$ [1].
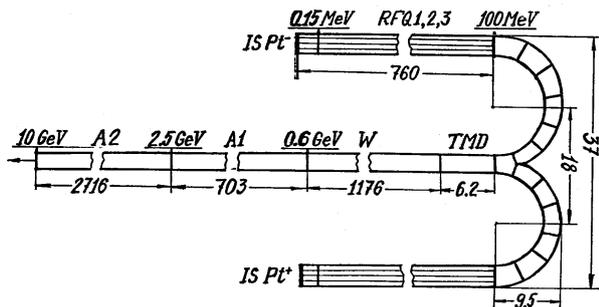

Figure 1: The total scheme of linac: *IS* -ion sources; *RFQ1,2,3* - injector channels; *TMD* - transverse matching device; *W* - Wideroe channel; *A1* and *A2* - Alvarez channels; all lengths are measured in meters.

Ion source

For ITEP Heavy Ion Fusion Project (IHIFP) it is necessary to have the beams of negative and positive heavy ions with cur-

rent about 50 mA. The existing now Negativ Heavy Ion Sources (NIS) provide the output current two order of magnitude less. Nevertheless, the simple theoretical consideration show the increase opportunity of NIS current up to requirement level to be realistic.

We are planing to organize our NIS investigation at the injector of the heavy ion RFQ linac (TIPr-1). We suppose to develop this investigation in two directions.

The first - a new version of NIS. As the prototype of this version we have chosen the MEVVA ion source version ITEP-90 [2].

The second, as a reserve variant, Plasma - Shutter NIS, has taken into account. For the effective surface 140 cm^2 as sputtering target, we hope to receive the heavy negative ion current about 100 mA. It is according to scaling law for plasma ion sources (H.V. Smith, Jr. Paul Allison, and J.D. Sherman - Los Alamos NL).

For IHIFP we plan to use eight ion sources of eight kinds of platinum ions ($Pt_{192}^{\pm}$, $Pt_{194}^{\pm}$, $Pt_{196}^{\pm}$, $Pt_{198}^{\pm}$) are divided into two symmetrical arrays according to the mass and charge sign of ion: four sources of positive ions and four sources of negative ions [1].

All sources produce identical parallel beams: ion energy of $0.15 \, MeV$, beam radius of $0.2 \, cm$, transverse emittance of $24 \, \pi \cdot cm \cdot mrad$ in each direction. Each source must provide the entry separatrix bucket of injector (momentum spread $\pm10\%$ and phase length $300°$) with an average pulse current of $130 \, mA$. The distance between beams in each array is $15 \, cm$. The distance between arrays (measured from the middle axes) is $36 \, m$. The sources of each array are positioned symmetrically with respect to the common axis of symmetry. The higher mass isotope the source is further from the common axis.

Injector

Each ion source is followed by its RFQ injector. All parallel channels are located in one horizontal plane. Four injector channels of each array may share the same vacuum system. The total length of RFQ injector is about $760 \, m$, output energy is $100 \, MeV$. The injector consists of four stages: RFQ buncher (RFQb) and three consequent RFQ accelerating channels (RFQ1, RFQ2, RFQ3) with different radio frequencies (RF). RFQb is essentially the initial part of RFQ1, but the electrodes in RFQb are modulated so that the separatrix length is constant and equal to $5.1 \, cm$. Characteristics of RFQ channels are presented in Table 1 where **b** is bunch length and **a** is beam radius. Mismatching of transverse and longitudinal oscillations due to "jumps" of RF is minimized by suitable choice of channel char-

Table 1: The stages of injector and main channel

	T	**L**	**V**	**RF**	$\varphi_{\mathbf{s}}$	**b**	**Δp/p**	**a**	ε/π
	MeV	m	kV	MHz	degree	cm	%	cm	$cm\cdot$ $mrad$
RFQb	1.1	12.2	190	6.25	37	5.0	3.9	0.5	9.1
RFQ1	15	140	190	6.25	37	8.3	0.62	0.5	2.4
RFQ2	50	127	320	12.5	47-37	6.2	0.46	0.5	1.3
RFQ3	100	416	400	25.0	45-30	9.1	0.29	0.5	0.9
Wideroe	600	1137	200	25.0	37	7.8	0.14	0.9	1.4
	GeV		**E** kV/cm						
Alvarez 1	2.5	684	35	75	37	4.1	0.13	0.9	0.7
Alvarez 2	10	2697	35	227	37	3.6	0.07	1.0	0.5

acteristics at boundary points. The RFQ3 channel is ended by special debunching cavity for reducing the momentum spread before the bending magnet. The length of the cavity is $65.1\ m$ that is a quarter of the period of the longitudinal oscillation. The cavity may be a continuation of RFQ3 with different modulation of electrodes. As a result the momentum spread at the exit of the injector is $\pm 0.1\%$ and the bunch length is $26.2\ cm$. The RF power consumed by beams in eight injectors for each stage is $(5.4 + 12.6 + 18)\ MW$ accordingly.

The bending and matching magnet arrangement

The eight ion beams are brought together into the main accelerating channel by the bending magnet arrangement. Transverse matching and focusing are achieved by suitable choice of the bending field index n in alternating gradient magnetic sectors and inclined face at the entry of the arrangement. The arrangement consists of 6 periods of alternating gradient magnets and of separate $12°$ bending magnet with uniform field. The period consists of 3 magnetic sectors: 2 outer ones with angle spacing of $7°$ and field index $n = -15$ and central sector with angle spacing $14°$ and $n = 17$. The first magnet of the first period has the inclined entry face with angle $12.15°$. According to the arrays of injector channels there are 2 separated magnet arrangements for positive and negative ions. The final $12°$ bending magnet with uniform field is common for all beams (both positive and negative ions). The bending field is $22.2\ kGs$ at an average radius of $9\ m$, the gap between magnetic poles is $6\ cm$. The lengths of the beam trajectories in bending magnets and phases of accelerating fields in injectors have been chosen so that all ion beams are positioned in the consecutive RF buckets of the single main accelerating channel. Because of the RF has been increased to 4 times as large as initial one the longitudinal distance between ion bunches of the identical kind is 4 wavelengths $(160\ cm)$. Thus it is possible to place each isotope in its own bucket. The bunches of the same isotope with opposite charges are shifted by half a wavelength $(20\ cm)$. Furthermore, in the Wideroe channel two bunches of the same isotope with opposite charges are placed in one RF period.

Transverse matching device

The bending magnet arrangement is followed by a transverse matching device to reduce the oscillation amplitudes in the main accelerating channel. The device consists of 6 quadrupole lenses with permanent magnets (for example $Sm - Co$). A sequence of elements in horizontal plane is L, F1, L, D1, L, D2, L, F2, L, F3, L, D3, L1. All drift lengths L are $50\ cm$, the last drift length L1 is $17\ cm$, thickness of each lens is $50\ cm$. Gradients are: in F1 and D1 - $2\ kGs/cm$, in D2 and F2 - $1.5\ kGs/cm$, in F3 - $1.3\ kGs/cm$, in D3 - $0.5\ kGs/cm$. The total length is $617\ cm$. At the exit of the matching device, the beam parameters are: horizontal size is $0.8\ cm$, vertical size is $0.4\ cm$, length of bunch is $27\ cm$, momentum spread is $\pm 0.1\%$.

Table 2: Matching devices before the stages of main channel

	L	**V**	$\varphi_{\mathbf{s}}$	**b**	**Δp/p**
	m	kV	deg.	cm	%
Wideroe	39.2	4.05	90	5.0	0.54
		E kV/cm			
Alvarez 1	19	8.0	90	3.2	0.32
Alvarez 2	19	11.2	90	3.1	0.17

The main channel

The main channel consists of 3 stages. The first one is a Wideroe accelerating structure, the second and the third ones are Alvarez accelerators with different RF. The design parameters are shown in Table 1. The initial part of each stage is a quarter-wave device for matching the longitudinal oscillation; its parameters are presented in Table 2. The total length of main channel is $4595\ m$. The focusing is realized by quadrupole lenses with permanent magnets too. The gradient of magnetic field in the lenses is ranged from 0.7 to $3.3\ kGs/cm$. The three stages of main channel require RF power of $(0.18 + 0.684 + 2.7)\ GW$ accordingly. The exit beam has an energy of $10\ GeV$, bunch length is $3.6\ cm$, momentum spread is $\pm 0.07\%$, horizontal emittance is $0.6\ \pi\cdot cm\cdot mrad$, vertical emittance is $0.4\ \pi\cdot cm\cdot mrad$, radius is less than $1.1\ cm$. The distance between identical ion bunches is $15.3\ m$. The total growth of the longitudinal phase space along

the linac is about 40%. The horizontal phase space increases by about 5 times, the vertical one by about 3.5 times. The calculations were made for ideal channels without misalignments and errors.

References

[1] D.G. Koshkarev, "Charge-Symmetric Driver for Heavy-Ion Fusion", IL Nuova Cimenta, Vol. 106 A, N 11 p. 1567, 1993.

[2] V.A. Batalin, J.N. Volkov, T.V. Kulevoy, S.V. Petrenko, Rev. Sci. Instrum. 65 (10) p. 3104, 1994.