LINEAR ACCELERATOR FOR PRODUCTION OF RADIOACTIVE BEAMS

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Abstract

In the Institute for Nuclear Research a new facility based on the primary proton beam of the meson factory is under development in order to obtain, to separate and to accelerate on-line radioactive isotopic ions up to energy of 6.5 MeV/amu with the intensity up to 10^{12} atoms/sec. The heavy ion CW linac consists of 2 types of accelerating structures: 27.12 MHz RFQ in the energy range from 1 keV/amu to 60 keV/amu and IH-structure from 60 keV/amu to a final energy of 6.5 MeV/amu. The most essential advantage of the Linac for production of accelerated radioactive beams in comparison with a cyclotron is a higher acceleration efficiency of ions with a minimum charge to mass ratio equal to 1/60. Practically 99% of the injected beam is accepted by the linac; acceleration occurs without beam losses. Successful development of the IH-structures with shunt impedances in the range of 200-300 MOm/m allows the linac to run in CW mode [1, 2]. The using of a stripper at 350 keV/amu to increase of charge-to-mass ratio does not destroy either the transverse or the longitudinal emittance.

Introduction

The proposed Linac consists of two types of accelerating structures: RFQ and IH-structure [3]. The RFQ accelerator provides almost 100% capture of the injected particles. For the electrode voltage U=100 kV the RFQ transverse normalized acceptance is equal to 1 $\pi \cdot$ mm $\cdot$ mrad for an rf frequency of f $\sim 25 MHz$. Beam specifications after the RFQ are $|\Delta\Phi| < 20°$, $|\Delta p/p| < 1\%$. Use of an RFQ for acceleration of ions with the ratio $q/A = 1/60$ to energies greater than $\sim$ 60 keV/amu is not efficient because it is limited to an acceleration gain of $\sim 4 keV/amu \cdot m$. The interdigital H-structure provides a gradient of $\sim 34 keV/amu \cdot m$. Therefore in the energy range (60- 350) keV/amu for ions with q/A=1/60, the IH-structure is preferable. Main problem for ion acceleration in this range is beam focusing. Several types of beam focusing in IH-structure were considered: 1. Alternating phase focusing; 2.Focusing with electrostatic quadrupole lenses placed inside the drift tubes; 3. Magnetic periodic focusing. Detailed consideration has shown that the most efficient structure consists of magnetic quadrupole lenses placed inside the drift tubes which are alternated with drift tubes without quadrupole lenses. To make technically achievable lens gradients, the drift tube length with quadrupole lens must be longer than $\beta\lambda$. Because the phase spread at the RFQ output is sufficiently small, the synchronous phase of the IH-tank can be chosen equal to $\phi = -25°$. The rf field level in the accelerating gaps must be low enough to avoid rf breakdown in the CW operation mode. The other restriction on the accelerating field is the rf power dissipation per unit length P'. For reliable operation of the rf tank the value of P' is equal to ~20-30 kW/m.

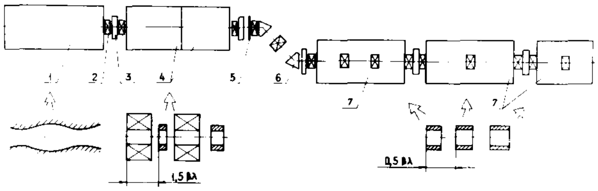

Figure 1: Schematic layout of the radioactive nuclides linear accelerator. 1 - RFQ resonator, 2 - focusing lenses, 3 -rebuncher, 4 - IH-structure tanks with magnetic periodically focusing, 5 - carbon foil, 6 - bending magnet, 7 -IH-structure with quadruplet housing.

Accelerator design

The layout of the radioactive nuclides linear accelerator is shown in Fig.1.

The compact bunches downstream of the RFQ have to be accelerated up to the stripping energy of 350 keV/am in IH-structure with magnetic quadrupoles periodically installed in every odd drift tube. By adjusting the edge shapes of the drift tubes with quadrupoles it is possible to keep the shunt impedance sufficiently high. The accelerating tank based on the IH-structure in the energy range of 60-350 keV/amu consists of two sections with separate rf excitation. The power consumption of each section is expected to be $\sim 35 kW$.

A charge state of $^{120}Sn^{2+}$ after the passing through a carbon foil at the energy of 350 keV/amu has been calculated in accordance to ref.[4]. The results are presented in Fig. 2. For subsequent acceleration, the charge state with q = +18 has been chosen. The ions with other charge states are separated and dumped using the bending magnet.

The accelerating tanks in the energy range 350-6500 keV/amu are based on the IH structure designed for a

Table 1: **Basic parameters of the radioactive nuclides accelerator**

N of tank	1	2	3	4	5	6
Type of tank	RFQ	IH	IH	IH	IH	IH
Focusing type	RFQ	FODO	FODO	QH	QH	QH
Input energy (keV/amu)	1	60	230	350	2500	4600
Output energy (keV/amu)	60	230	350	2500	4600	6500
Charge (q/A)	1/60	1/60	1/60	3/20	3/20	3/20
Operating frequency (MHz)	27.15	27.15	27.15	54.3	108.6	108.6
$E_0 \cdot T$ (kV/cm)	-	27	27	23.4	22.5	20.3
Tank length (m)	5.5	7.5	7.2	8.4	8.1	8.0
Eff. shunt impedance (MOm/m)	-	310	180	250	(230)	(190)
Rf power consumption (kW)	44	35	60	130	140	135

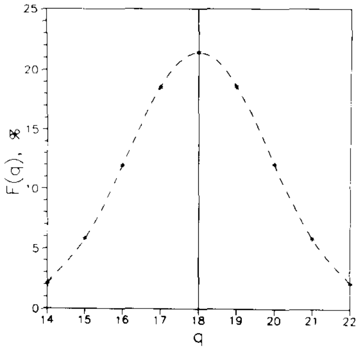

Figure 2: Charge distribution of the $^{120}Sn^{2+}$ ions downstream the stripping foil.

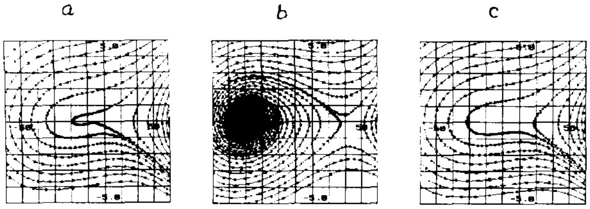

Figure 3: Phase trajectories on the plane $(\phi, \Delta\beta/\beta)$ for IH-structure with $\phi_s = 0$ (a,c) and $\phi_s = -30°$(b).

synchronous phase $\phi_s = 0$. The phase trajectories in the plane $(\phi, \Delta\beta/\beta)$ in various points along the tank with the energy from 350 keV/amu up to 2500 keV/amu are shown in fig.3. During the acceleration the particles are moved along the phase trajectories as shown in fig. 3a,c. To rotate a bunch downstream of the focusing quadruplet housing (QH), the synchronous phase is set to -30°. The focusing housing is placed at a minimum of the rf field, therefore the shunt impedance of the tank is not be worsened. Due to the small drift tube diameter in the accelerating region, a maximum value of the shunt impedance is provided [2]. Even though there is no separatrix in the IH-structure tank calculated for $\phi_s = 0$, acceptance in it shown in fig. 4. By suitable matching of

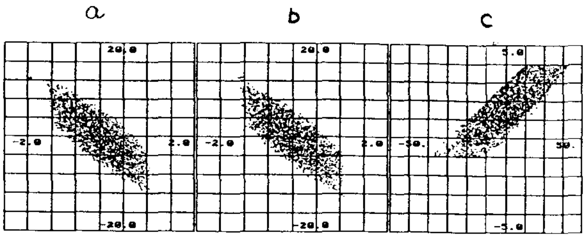

Figure 4: Transverse (a,b) and longitudinal (c) acceptance of the IH-structure with injection energy 350 keV/amu.

the longitudinal phase parameters of the injected beam, it is possible to accelerate the bunches with $\Delta\Phi = 20°$ and $\Delta\beta/\beta = 1.5\%$. A normalized transverse acceptance of that tank exceeding 1 $\pi \cdot$ mm $\cdot$ mrad is shown in fig. 4. The basic Linac parameters are listed in the table 1.

Rf parameters study of IH-structure

The 1:3 scale models of the each type of IH-structure tank have been developed and manufactured. In Figs 5,6, the photographs of the 2 type IH-structure models are shown. The resonant frequency as well as the uniform accelerating field distribution are provided by changing the angle between the conducting side stems. Additionally, the diameter of several drift tubes have been changed to get the required accelerating field distribution. A uniform distribution of the electric field can be obtained coarsely by use of the resonance tuning elements, which are the short plungers between the stem bar and the cylindrical surface of the tank. These plungers are successfully used to form the proper field distribution for the IH-structure with the focusing elements housing (Fig.6).

The accelerating field distribution in the model of tank #2 (see Table 1) is shown in Fig.7. Similar distribution for the tank #4 model is presented in Fig.8. A ratio of the electric shunt impedance to a quality

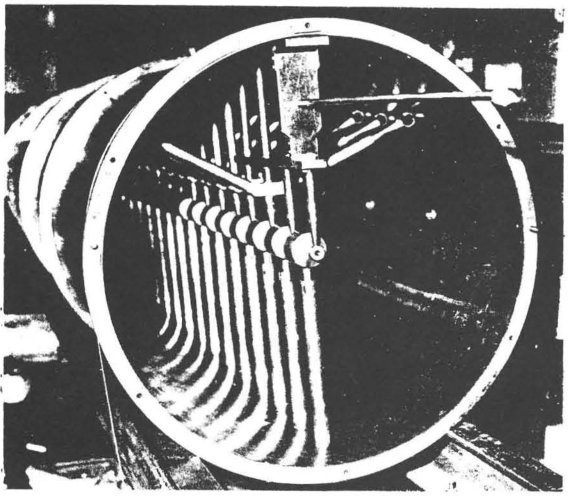

Figure 5: The 1:3 model of the tank #2

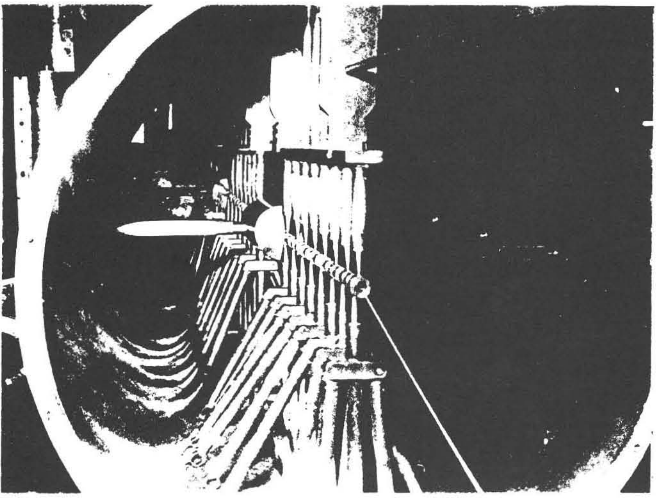

Figure 6: The 1:3 model of the tank #4

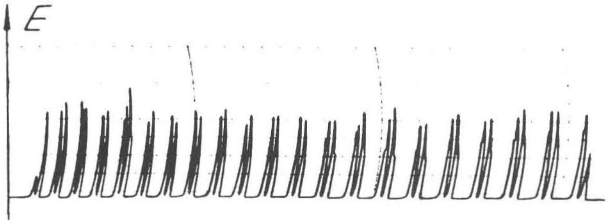

Figure 7: Accelerating field distribution (tank #2)

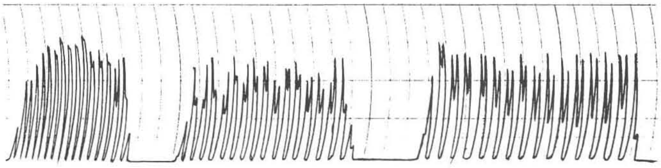

Figure 8: Accelerating field distribution (tank #4)

factor has been measured on the model. In accordance with our experience this value is kept for full scale tank. Knowing the expected value of the quality factor for the full scale model, it is possible to find the effective shunt impedances and to estimate the power consumption. These numbers are presented in the Table 1.

Conclusion

A Linac for acceleration of radioactive nuclides based on RFQ and inter digital H-type structures is proposed. The basic features of this Linac are:
- CW operation;
- practically 100% capture and the acceleration with minimum losses;
- small ratio q/A=1/60 of the injected ions;
- a single stripping foil at an ion energy of 350 keV/amu;
- using the IH-structure with a large shunt impedance for a moderate rf power consumption (~600 kW) and Linac length (~45m).

References

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