DEVELOPMENT OF A RADIOACTIVE NUCLIDES ACCELERATOR AT THE MOSCOW MESON FACTORY

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Abstract

In the Institute for Nuclear Research the new facility based on the primary proton beam of the meson factory is under development in order to obtain, separate and accelerate on-line radioactive isotopic ions up to energy of 6.5 MeV/amu with the intensity up to 10^{12} atoms/sec. In order to accelerate radioactive beam with initial ratio q/A>1/60 with good efficiency the heavy ion CW linac is considered which consists of 2 types of accelerating structures: 27.12 MHz RFQ at the energy range from 1 keV/amu to 60 keV/amu and IH-structure from 60 keV/amu to final energy of 6.5 MeV/amu.The operating frequencies of IH structure are 54.24 MHz and 108.48 MHz. The only carbon stripper at the energy of 350 keV/amu is foreseen to increase q/A up to 3/20.The last achievements in a development of RFQ and IH structures result to relatively small accelerator length - 45m and power dissipation - 1 MW.

Introduction

A new area of the nuclear matter study is opening in experiments with accelerated radionuclide beams. Experiments of that kind followed by express methods of research allow to study the properties of nuclides with short half-lives removed far from the stable β-line and being in extreme status of the nuclear matter [1,2].

Most essential advantage of the Linac for production of accelerated radioactive beams in comparison with cyclotron is a highest acceleration efficiency of ions with a minimum charge to mass ratio which is equal to 1/60. Practically ~99% of the injected beam is accepted by linac and acceleration occurs without beam losses. Successful development of the IH structures [3-9] with shunt impedances in the range of 100-300 MOm/m allows to realize the linac in CW mode. The using of stripper at the energy of 350 keV/amu does not destroy both transverse and longitudinal emittances, at the same time it allows to increase acceleration gain.

Description of the Proposed Accelerator

RFQ accelerator provides almost ~100% capture of the injected particles [10]. For the electrode voltage U=100kV the normalized acceptance is equal to 1 πmm mrad if the rf frequency is chosen f ≈ 25 MHz. Beam specifications after RFQ are $|\Delta\Phi|<20^{o}$, $|\Delta P/P|<1\%$. The using of RFQ for acceleration of ions with the ratio q/A = 1/60 up to higher energies than ~6.0 keV/amu is not efficient because it provides of the acceleration gain of ~4 keV/amu·m only, meanwhile the inter digital H- structure provides about one of ~34 keV/amu·m. Therefore at the energy range of (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 a beam focusing. It was considered several types of beam focusing in IH-structure: 1. Alternating phase focusing; 2.The focusing with electrostatic quadrupole lenses placed inside the drift tubes; 3. Magnetic periodic focusing. The detail consideration has shown that the most efficient structure consists of magnetic guadrupole lenses placed inside the drift tubes which are alternated with the drift tubes without quadrupole lenses. To make technically achievable gradients of the lenses the drift tube length with quadrupole lens must be longer on the value of βλ. Because of the phase spread at the RFQ output is sufficiently small, the synchronous phase of IH-tank tank can be chosen equal to $\varphi=-25^{o}$. Rf field level in accelerating gaps must be determined from condition of the absence of rf breakdown in CW operation mode. Other restriction on accelerating field is the rf power dissipation per unit length P'.For the reliable operation of rf tank the value of P' is accepted equal to ~30 kW/m how it was done in Munich heavy ion post accelerator [7].The rf field in the gap is determined from expression:

$$E_g = \frac{\sqrt{Z_{eff}\, P'}}{\alpha \cdot T \cdot \cos\varphi} ,$$

where Z_{eff} is effective shunt impedance, α is a ratio of gap width to period length. In accordance to ref [7] the optimum α value for IH-structure is .5 leading to maximum shunt impedance.

The layout of the radioactive nuclides linear accelerator is shown in fig.1. The resonant frequency of RFQ is determined by concentrated capacitance and inductance. Schematic view of the RFQ section is shown in fig.2. The calculated capacitance of each section is 68.3 pF and inductance is 490 nH that corresponds to 27 MHz frequency.

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The compact bunches downstream RFQ have to be accelerated up to the stripping energy of 350 keV/amu in IH-structure with magnetic quadruples periodically installed in every odd drift tube. A maximum value of gradient in focusing lenses is 10 kG/cm which corresponds to magnetic induction of 10 kG on the pole. A preliminary consideration shows that by choosing of edge shapes of the drift tubes with quadrupoles it is possible to keep the shunt impedance sufficiently high. The accelerating tank based on 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 ~150 kW.

A charge state of $^{120}Sn^{+2}$ after the passing of a carbon foil has been calculated in accordance to ref [11]. The results are presented in fig. 3. For subsequent acceleration the charge state with q = +18 was chosen. The ions with other charge states are separated and dumped using the bending magnet.

The accelerating tanks in the energy range of 350-2500 keV/amu based on IH structure designed for a synchronous phase $\varphi_s=0$. The phase trajectories in the plane$(\varphi,\Delta\beta/\beta)$ in various points along the tank with the energy from 350 keV/amu up to 2500 keV/amu are shown in fig.4. During the acceleration the particles are moved along the phase trajectories shown in fig. 4a,c. To rotate a bunch downstream the focusing quadruplet the focusing quadruplet housing is placed in a minimum of rf field, therefore the shunt impedance of the tank is not be worsen. Due to small drift tube diameter in the accelerating region a maximum value of Z_{eff} is provided[8].

Despite of no separatrix exists in IH-structure tank calculated for synchronous acceptance in it shown in fig. 5. By suitable matching of longitudinal phase parameters of the injected beam it is possible to accelerate the bunches with $\Delta\Phi= \pm 20^0$ and $\Delta\beta/\beta = \pm 1.5\%$. A normalized transverse acceptance of that tank exceeding 1 πmmmrad is shown in fig. 5. The basic Linac parameters are listed in the table.

TABLE

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	Quadruplet		
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	27	27	54	108	108
E_0T (kV/cm)	-	27.0	27.0	23.4	22.5	20.2
Tank length (m)	5.53	7.51	7.06	8.42	8.10	8.01
Number of accelerating cells	228	42	27	50	61	49
Synchronous phase (deg)	-90÷ ÷-30	-25	-25	0	0	0
Eff. shunt impedance (MOm/m)	-	92	50	186	168	139
Rf power consumption (kW)	44	150	150	181	188	185
Rf power loss per unit length (kW/m)	8	20	21.3	29.5	30.1	29.5

E_0 is average field on the length of $\beta\lambda/2$.

Rf power system

Basic features of the rf system are following:

1. CW rf power generation up to 150-200 kW at the three multiple frequencies.
2. A requirement of the acceleration of ions with various charge to mass ratio that results to the necessity of the output rf power variation in a wide range.
3. The absence of beam loading and CW operation mode allow to use sufficiently simple and slow feedback system.

It turns out that most suitable rf generators satisfying for specifications mentioned above except of the resonant frequencies are those developed for UNK project using the triode GU-101A as an output cascade, which can be easy modified to the lower frequency. Now 27 MHz generator is under development for the test facility.

Conclusion

The Linac for acceleration of radioactive nuclides based on RFQ and interdigital H-type structures is proposed. Basic features of the Linac are:

- CW operation;
- practically 100% capture and acceleration with minimum losses;
- small ratio q/A=1/60 of the injected ions;
- using the only stripping foil at the ion energy of 350 keV/amu;
- using IH-structure with a high value of shunt impedance resulting to a moderate rf power consumption (≈930 kW) and Linac length (~45m).

References

1. A.S.Iljinov and V.M.Lobashev. Proceedings of IVth All-Union Workshop on the Program of Experiments on Moscow Meson Factory. Moscow, 1986, p. 22. (In russian).
2. G.N.Vjalov et al. Proceedings of Workshop INES-89, Moscow, 1989, v.1, p.279.
3. V.A.Bomko et al. Study of the heavy ion accelerating structures, CNIIatominform, M., 1988. (In russian).
4. O.A.Valdner et al. VANIT, Nuclear physical researches, v.5 /5/, p.16. (In russian).
5. E.Nolte et al NIM, 158 (1979), p. 311-324.

6. E.Nolte et al NIM, 201 (1982), p. 281-285.
7. U.Ratzinger et al. NIM, A 263 (1988), p. 261-270.
8. U.Ratzinger. LINAC-88, October 3-7, 1988, p. 185.
9. T. Hattori et al, LINAC-86, June 2-6, 1986, p. 377.
10. I.M.Kapchinskij, V.A.Tepljakov, PTE, No 2, 1970, p.19.
11. M.A.Mcmaham et al. Proceedings of the 1989 IEEE PAC, No 1, Chicago, IL, p. 536.

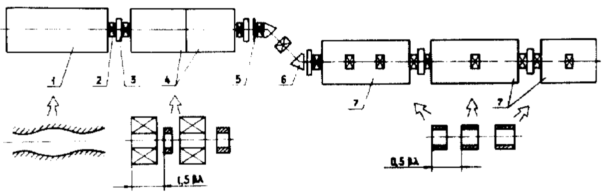


Fig.1. Schematic layout of the radioactive nuclides linear accelerator. 1 - RFQ resonator, 2 - focusing lenses, 3 - rebuncher, 4 - IH-structure tanks with magnetic periodically focusing, 5 - carbon foil, 6 - bending magnet, 7 - IH-structure with quadruplet housing.

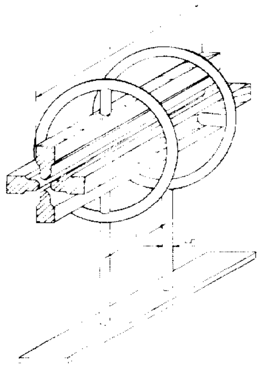


Fig.2. View of one section of the RFQ structure.

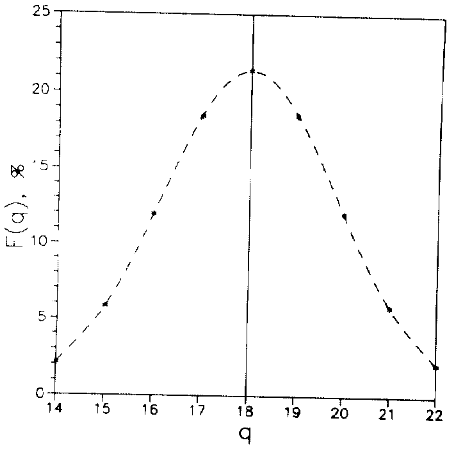
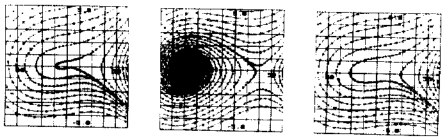
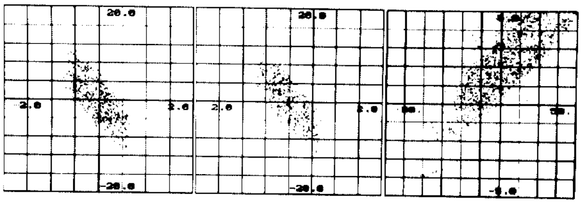


Fig.3. Charge distribution of the ^{120}Sn ions downstream the stripping foil.



a b c

Fig.4. Phase trajectories on the plane (φ, $\Delta\beta/\beta$) for IH-structure with $\varphi_s=0$ (a,c) and $\varphi_s=-30^{\circ}$ (b).



a b c

Fig.5. Transverse (a,b) and longitudinal (c) acceptance of the IH-structure with injection energy 350 keV/amu.