DESIGN PROBLEMS OF HIGH ENERGY CW ION LINAC

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Abstract

The scheme and parameters of a transmutation linac and also the problems associated with the construction of an accelerating system, of an RF power supply system and of an initial part capable of accelerating the proton beam with the current of 0.3 A are described.

Introduction

According to one of the promising methods of nuclear transmutation of long-living nuclear wastes, powerful fluxes of the thermal neutrons are generated at the target bombarded by a proton beam with the energy up to 1.5 GeV and the current up to 0.3 A (the beam power up to 150 MW). Such a beam may be produced by a continuous regime linac. The three world powers - the USA, Russia and Japan work actively on the wastes transmutation methods linac [1-5].

The transmutation linac scheme and systems are similar to those of Meson Facilities of the Los-Alamos National Laboratory and of the Institute for Nuclear Research of the Russian Academy of Sciences. The project and the main systems of the INR RAS have been developed by the Moscow Radiotechnical Institute. The experience accumulated in the course of the Meson Facility linac construction gives ground to think that transmutation linac projects are practicable.

Besides linac scheme and parameters, the three original systems, developed in the MRTI will be presented in the article: the high-energy accelerating structure, superpowerful RF generator - Regotron and the initial linac part with strong longitudinal magnetic field focusing.

Scheme and parameters

The linac consists of the three parts. In the initial part the strong longitudinal magnetic field focusing is used. Its operational frequency is 330.3 MHz and the energy ranges from 0.2 MeV at the input to 3 MeV at the output. The first part is a drift tube linac with the same operational frequency and the output energy of 75 MeV. In the second part the disk and washer accelerating structure is used. Its operational frequency is 991 MHz with the accelerating rate of 1 MeV/m.

A high accelerated current up to 300 mA is required so as to achieve high efficiency of the accelerating structure operation (about 90%). If the required particles current at the target is lower, the beam at the linac output may be divided. The odd frequency ratio (3) allows to accelerate H^+ and H^- beams at the same time.

The main linac parameters are shown in Table 1.

Table 1

The main linac parameters

Parameter	Linac part		
	Initial	First	Second
Inj. energy, MeV	0.2	3	75
Output energy, MeV	3	75	1500
Frequency, MHz	330.3	330.3	991
Length, m	3	70	140
Structure	OVR	DTL	DWS
Accel. rate, MeV/m	1	1	1
Aperture diam., mm	13 → 20	30	30 → 40
RF power for beam acceleration, MW	0.84	21.6	427.5
RF power losses in the walls, MW	0.15	4	75
Focusing structure	LMF*	FODO	FODO
Focusing lenses type	SCS	PMQ	PMQ
Limit current, A	0.9	0.9	1.0
Accelerated current, A	0.3	0.3	0.3
Acceptance, cm·mrad	2.5π	3.0π	4.5π
Emittance, cm·mrad	0.5π	1.0π	3.0π
Bunch phase length**	60°	25°	20°
Synchronous phase	90° → 40°	30°	30°

* - longitudinal magnetic field
** - 330.3 MHz

Disc and Washer Accelerating Structure (DWS)

The disc and washer accelerating structure invented and developed in the MRTI and used in the Meson Facility of the INR RAS, has a number of advantages, which are as follows: high coupling coefficient of the neighboring cells (ranging from 25% to 50%), high effective shunt impedance, high stability relative to manufacturing errors, improper tuning and beam loading.

The only defect of the structure is that parasitic modes are generated in close vicinity of the operational one, caused by stems, supporting washers. Parasitic modes, having azimuthal variations, are removed with the aid of combined T-shaped slits in the washers [6]. In May of 1992 the beam at the Meson Facility was accelerated up to the energy of 250 MeV. The DWS structure operated with a good stability.

Regotron

The overall RF power consumption of the transmutation linac accelerating structure with the aforementioned parameters amounts to about 500 MW. To produce this power, five hundred 1 MW – generators are required. The reliability of the linac operation might be considerably increased if the generator output power was at least 5 MW, as it is made in our project. The new generator type – regotron – was proposed in the MRTI [7].

Regotron is an RF generator in which is used a powerful relativistic electron beam with a low perveance and a distributed power take-off system, consisting of a number of uncoupled resonators. The principle of autophasing is also used in the regotron, which keeps the bunches intact as they are decelerated. The autophasing is arranged by couples of resonators, the first of which, tuned to the operational frequency, takes the power off the beam, while the second one, detuned to the angle approaching $\pi/2$. bunches the beam without changing its average energy.

When the beam is accelerated by the RF field, the autophasing results in suppression of phase oscillations and the bunches phase length decreases. When the beam is decelerated the phase oscillations amplitude and the bunch phase length grow, which may result in the diminishing of the first harmonic of the beam and the break-down of the deceleration.

Investigations of particle dynamics showed that the phase dimensions of a bunch change as follows: $x \sim l_n/(\varphi_n^3 R_n T_n)$, where l_n is the distance between the n-th and the (n-1)-th resonator, φ_n is the synchronous particle phase in the n-th resonator, R_n and T_n are the shunt impedance and transit time factor, correspondingly. The bunch swelling may be considerably neutralized by the proper choice of l_n and R_n parameters. Computations showed that the beam power take-off efficiency may be increased up to 85..90% by the proper choice of parameters

For the time being the pulsed prototype of the regotron with the operational frequency of 991 MHz is under construction in the MRTI. Its major parameters are given in the Table 2.

Table 2

The Main Regotron Prototype Parameters

Input energy	0.5 MeV
Current	15 A
Frequency	991 MHz
Excitation power	0.5 kW
Output power	5.2 MW
Efficiency	70%
Number of power outputs	7
Overall length of RF section	8 m
Overall number of resonators	18

All the three bunching resonators of the regotron prototype have been manufactured and tuned.

The initial linac part with the strong longitudinal magnetic field focusing

The RFQ focusing ensures the limit accelerated current of 100...150 mA, which is insufficient for a one beam linac which is the most preferable, as far as reliability is concerned. The strong longitudinal magnetic field focusing in the initial linac part allows to increase the limit current for the same injection energy by an order of magnitude [8]. The high accelerating field and synchronous phase ensure the high limit current. Protons are accelerated in a "warm" compact opposite-vibrator resonator (OVR).

Mathematical simulations of the high-current beam dynamics revealed the following dependence of capture coefficient on the beam space charge density (frequency ~ 300 MHz, injection energy ~ 200 keV).

Injected current	Space charge density	Accelerated current	Capture
A	A/cm^2	A	%
1	1.5	0.45	75
2	3.0	0.85	70
3	4.5	0.95	55

From this one may incur that the increase of charge density over 3.0 A/cm^2 makes no sense.

The pulsed model of a proton linac has been constructed and investigated. It has the following parameters: injection energy – 0.1 MeV, output energy – 1.5 MeV, frequency – 196.8 MHz, maximum accelerating field amplitude – 3.7 MV/m, magnetic field induction – 7.6 T. The accelerated protons current in the model amounts to 0.4 A.

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