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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Linac part</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>First</td>
</tr>
<tr>
<td>Energy, MeV</td>
<td>0.2</td>
</tr>
<tr>
<td>Output energy, MeV</td>
<td>3</td>
</tr>
<tr>
<td>Frequency, MHz</td>
<td>330.3</td>
</tr>
<tr>
<td>Length, m</td>
<td>3</td>
</tr>
<tr>
<td>Structure</td>
<td>0VR</td>
</tr>
<tr>
<td>Acceler. rate, MeV/m</td>
<td>1.0</td>
</tr>
<tr>
<td>Aperture diam., mm</td>
<td>20</td>
</tr>
<tr>
<td>RF power for beam acceleration</td>
<td>0.84</td>
</tr>
<tr>
<td>RF power losses</td>
<td>1.0</td>
</tr>
<tr>
<td>Focusing structure</td>
<td>LMF</td>
</tr>
<tr>
<td>Focusing lenses type</td>
<td>SCS</td>
</tr>
<tr>
<td>Limit current, A</td>
<td>0.9</td>
</tr>
<tr>
<td>Accelerated current, A</td>
<td>0.3</td>
</tr>
<tr>
<td>Acceptance, cm·mm²</td>
<td>2.5n</td>
</tr>
<tr>
<td>Emittance, cm·mm²</td>
<td>0.5n</td>
</tr>
<tr>
<td>Bunch phase length</td>
<td>25°</td>
</tr>
<tr>
<td>Synchronous phase</td>
<td>90°</td>
</tr>
</tbody>
</table>

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 servenade 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 π/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: \( x \sim l / \langle \rho R T \rangle \), where \( l_n \)
is the distance between the \( n \)-th and the
(\( n-1 \))-th resonator, \( \rho_n \) 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>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output power</td>
<td>5.2 MW</td>
</tr>
<tr>
<td>Efficiency</td>
<td>70%</td>
</tr>
<tr>
<td>Number of power outputs</td>
<td>7</td>
</tr>
<tr>
<td>Overall length of RF section</td>
<td>8 m</td>
</tr>
<tr>
<td>Overall number of resonators</td>
<td>18</td>
</tr>
</tbody>
</table>

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).

<table>
<thead>
<tr>
<th>Injected Space charge</th>
<th>Accelerated Capture current</th>
<th>Density</th>
<th>current</th>
<th>A/cm²</th>
<th>A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.5</td>
<td>0.45</td>
<td>75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>3.0</td>
<td>0.85</td>
<td>70</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>4.5</td>
<td>0.95</td>
<td>65</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

From this one may incur that the
increase of charge density over 3.0 A/cm²
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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