DESIGN STUDY OF 15 MEV HIGH CURRENT RF FOCUSED DEUTERON LINAC FOR ITEP NEUTRON GENERATOR

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Abstract

Different structural schemes for medium energy high current deuteron linac are considered. The linac scheme consisting of RFQ and RF crossed lens (RFCL) sections [1] is proposed. A method of ion focusing by decelerating RF quadrupole fields is used in the RFCL sections. The method permits to receive a radial stability region up to 360^0 and independent on particle energy focusing strength. Basic advantages of the proposed scheme are shown to be the high acceleration rate, low transition energy between the RFQ and RFCL sections, and simplicity of the RFQ-RFCL beam matching.

1 INTRODUCTION

At the present a research neutron source consisting of a linac with an average current of 0.5 mA and a beryllium target is developed in ITEP. Neutrons received in the neutron source can be used for modeling of subcritical blanket system, neutron physics, transmutation of radioactive wastes, and study of radiating materials. The 15 MeV deuteron linac including RFQ and high acceleration rate RF focused section is considered as a driver for the neutron source. Use of magnetic quadrupoles for deuteron focusing is inefficient in the given energy range. A variant of neutron source based on 36 MeV proton linac consisting of RFQ and DTL is also considered in paper [2]. Below different structural schemes for medium energy high current ion linac with RF focusing are considered.

2 LINAC STRUCTURAL SCHEMES

Low injection energy, compactness, constructive simplicity and reliability of accelerating structure, radiating safety is taken into consideration, when a linac structural scheme is chosen. Besides technological linac systems should be accommodated in existing room of ITEP reactor complex. Basic requirements for the linac are given in table 1.

A structural scheme of the linac is shown in fig. 1. The linac contains a pulse deuteron injector (d^+), a low energy beam transport line (LEBT), RFQ for bunching and preliminary acceleration of the beam, a main part of accelerator (MPA) with high acceleration rate, a medium energy beam transport line (MEBT) for minimization of particle losses at transition between sections, high energy beam transport line (HEBT) including a system of bend magnets for delivering the beam to a beryllium target.

Table 1: Linac design parameters

Ion	deuteron
Input energy	35 keV
Output energy	15 MeV
Pulse beam current	50 mA
Radio Frequency	148.5 MHz
Linac length	<8 m

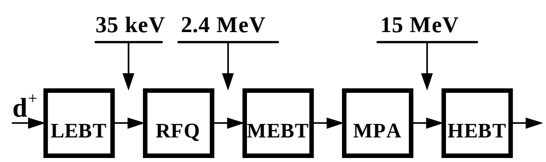

Figure 1: The deuteron linac structural scheme.

Let us consider different variants of the MPA (Fig.2).

2.1 RFQ-APF linac scheme

The APF (Fig.2a) is chosen as the first variant of the MPA. The RFQ and APF combination problem is paid special attention in beam dynamic calculations. The minimum transition energy between the RFQ and the APF is chosen equal to 2.4 MeV. The choice provides a required beam current and an equality of a longitudinal RFQ output emittance to a longitudinal APF acceptance. Design parameters of 2.4 MeV deuteron RFQ is presented in table 2.

Table 2: Design parameters of deuteron RFQ

Input energy	35 keV
Output energy	2.4 MeV
Radio Frequency	148.5 MHz
Current limit	100 mA
Minimum aperture radius	3.5 mm
Modulation	1.00÷1.95
Longitudinal phase advance	40.8 deg
Output momentum spread	±1.4%
Output phase width	40 deg
Transverse phase advance	42.0 deg
Normalized acceptance	0.28π cm·mrad
Linac length	2.86 m

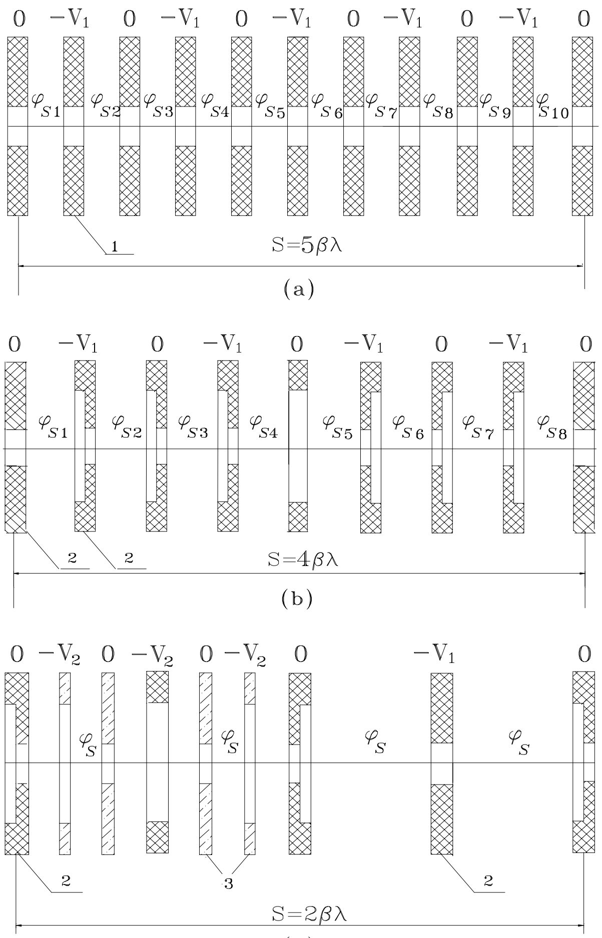

Figure 2: First periods for the MPA variants: APF (a), APQF (b), RFCL (c); 1, round aperture drift tubes; 2, rectangular aperture drift tubes; 3, two-electrode RF crossed lenses.

The deuteron bunches at the RFQ output have phase width of 40^0 and momentum spread of ±1.4% for zero current (Table 2). The APF channel separatrix with phase width of 80^0 allows to capture bunches with momentum spread of ±0.8 % (Fig.3). Therefore to obtain a longitudinal matching between the RFQ and the APF a debuncher is required.

The transverse matching sections is complicated because of different field symmetry in the RFQ (quadrupole) and in the APF (axially symmetric). To capture the beam without particle losses it is necessary 6D-matching between sections, that represents a separate problem. The MEBT should contain as a minimum four quadrupole lenses and a debuncher. In general case, the parameters of a matching line depend on beam current.

The focusing strength of APF system decreases with particle energy, that results in necessity of a focusing period lengthening. This effect causes a beam emittance growth in APF due to discontinuities of instantaneous values of transverse tunes at the joint points of focusing periods.

For 50 mA matched beam with emittance of 0.1π cm·mrad (0.4 normalized acceptance value) it is possible to obtain transmission efficiency near to 100% in the APF by increase of a channel aperture radius from 7.5 to 10 mm. The RFQ-APF linac can be considered as possible variant, if only a problem of 6D-matching between sections will be successfully solved.

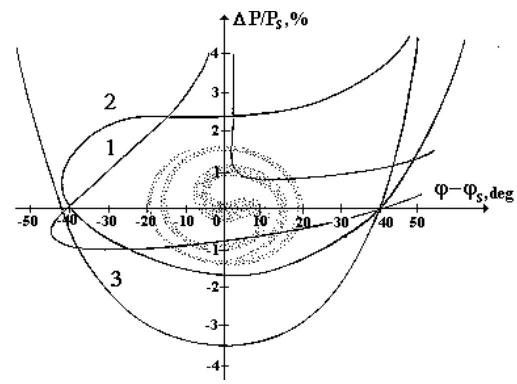

Figure 3: Phase portrait of beam at the RFQ output and longitudinal acceptances of the MPA with APF (1), APQF (2) and RFCL (3).

Further the transmission efficiency and parameters given in table 3 for each MPA structure are accepted the same as for the APF.

Table 3: Common parameters of the MPA

Input Energy	2.4 MeV
Output Energy	15 MeV
Radio Frequency	148.5 MHz
Phase width of separatrix	80 deg
Current limit	200 mA
Peak field in gap	160 kV/cm

2.2 RFQ-APQF linac scheme

The alternating phase quadrupole focusing (APQF) [3] system (Fig.2b) is chosen as second variant of the MPA. The APQF average focusing period length can be reduced compared with the APF (Table 4) since the APQF has higher focusing strength. That allows to provide a phase capture of particles with a momentum spread of ±1.8% (Fig.3). Thus conditions for longitudinal beam matching between the RFQ and the APF are satisfied and a debuncher is not required. However the focusing strength in APQF decreases with particle energy as well as in APF, that results in necessity of a focusing period lengthening. This effect causes a beam emittance growth in APQF as well as in APF.

Table 4: The MPA design parameters

PARAMETER	APF	APQF	RFCL
Length, (m)	3.533	2.718	2.355
Acceleration rate, (MeV/m)	3.6	4.6	5.3
S/βλ	5÷6	4÷6	2
Aperture radius, (mm)	7.5÷10	6.7÷8.5	5.0
Longitudinal phase advance, (deg)	80÷64	80	43.5
Momentum spread, (%)	±0.8	±1.8	±3.5
Transverse phase advance, (deg)	83÷66	83	45
Normalized acceptance, (cm·mrad)	0.44π	0.40π	0.38π

Transverse matching between sections becomes simpler since the RFQ and APQF fields have the same quadrupole symmetry. In this case, it is need 4d-matching between the RFQ and the APQF for total beam capture. Advantages the APQF over the APF in a focusing strength were also displayed as reduction of the section length (1.3 time) and the channel aperture (Table 4). Therefore the RFQ-APQF scheme is more advantageous then the RFQ-APF one.

2.3 RFQ-RFCL linac scheme

Problems of beam emittance growth and beam matching between sections can be successfully resolved by use of RF crossed lens (RFCL) [1] sections. A method of ion focusing in linac by RF decelerating fields of crossed lenses permits to obtain energy-independent focusing strength and high acceleration rate. Different structures of a RFCL focusing period are considered. The 2βλ focusing periods in the best way satisfy to design requirements and allow to receive transverse stability of particle motion inside the separatrix. The FDOO structure of focusing period with arrangement of two crossed lenses in two first gaps of accelerating system, formed by rectangular aperture drift tubes, is shown in Fig.2c. The proposed FDOO period has enough simple voltage distribution on the lens electrodes and drift tubes in comparison with other types of periods (for example FODO) at insignificant decrease of focusing strength (less than 10 %). The MPA with the RFCL contains six 2βλ FDOO periods, that allows to receive a momentum spread of ±3.5 % (Fig. 3). At the same time, output RFQ transverse emittance and RFCL radial acceptance are good superposed and it is possible to achieve the 6D-matching of the RFQ and the RFCL without the MEBT by choice of the RFCL parameters.

The transverse phase advance is kept constant along the RFCL channel, that provides unchangeable a beam radius along section. A ratio of radial and longitudinal phase advances in each focusing period is not less than 1.03, that essentially weakens a coupling between radial and phase oscillations. A required number of RF crossed lenses changes from two in the first focusing period up to six in the last one.

A RFCL application allows does not use the MEBT, essentially reduce a channel aperture (1.5-2 time) and a MPA length (1.5 time) in comparison with the APF (Table 4). The RFCL has a large longitudinal acceptance, therefore it is possible to decrease transition energy between the RFQ and the RFCL up to 1-1.5 MeV and to reduce a total linac length.

3 CONCLUSION

The proposed RFQ-RFCL scheme for medium energy high current ion linac permits to receive a radial stability region up to 360^0 and independent on particle energy focusing strength, as well as large current limit at low injection energy and high acceleration rate. The important advantages of the given scheme are MEBT absence, reducing of transition energy between sections, and increasing of linac acceleration rate. Therefore the deuteron RFQ-RFCL linac scheme for the neutron generator is the most preferable.

REFERENCES

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