THE NEW CONCEPTS IN DESIGNING THE CW HIGH-CURRENT LINACS

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The concepts in designing of the two types of high-current proton (deuteron) linacs having the electronuclear purpose with the output energy about 1 GeV and currents 200-300 mA (the first type) and 10 mA (the second type) are developed. The major problems arising in both cases is ensuring high reliability and efficiency of linacs. For the first type the high reliability is mainly connected with solving of the problem of minimizing the particles losses down to the level of 10^{-5} and of building the reliable superhigh-power RF power supply system. For the second type the problem of increasing the efficiency is of major importance. In the report the ways to solving of these problems by means of using the superconducting solenoidal focusing together with the optimized RF power supply systems (for the first linac type) and the superconducting accelerating cavities (for the second type) are shown.

I. INTRODUCTION

Design concepts of linear accelerators with the 1 GeV energy, 250 mA and 10 mA currents are considered.

In the first case (250 mA current) the general problems are provision of high reliability and efficiency, as well as radiation purity. In the present state of the technique reliability and efficiency are dictated by solving the problems of superhigh RF power supply system design and essentially lossless beam (10^{-5}) transport along the length of accelerator [1]. The solving of these problems provide radiation purity as well [2]. As discussed in MRTI papers [1,3] the number of RF power supply channels may not exceed one hundred for high reliability provision. This limitation demands design of RF amplifiers with output power up to 4...5 MW. For this purpose devices named "regotron" have been designed in MRTI [4,8]. With efficiency of about 70% the problem of high efficiency of the linac possess a solution. For the solving of the problem of lossless beam transport the focusing along main linac part based on superconducting solenoids was proposed. This version is considered in Part 2.

In the second case (10 mA current) the problem of high efficiency is brought to the fore. Estimations carried out in MRTI bring out that linac version with superconducting accelerating cavities is preferable. The concept of such linac is considered in Part 3.

II. LINEAR ACCELERATOR WITH SUPERCONDUCTING SOLENOIDS

The considered concept of the linac with 250 mA current is the further outgrowth of the MRTI quests [1-8] for linac for transmutation of long-living radioactive wastes of nuclear reactors. Novelty of this concept is associated with the use of superconducting solenoid focusing in the main accelerating part. It provides a possibility to reduce beam losses to the level of 10^{-5} .

Beam transport along the length of accelerator with minimal losses should be closely studied. The most limiting regions are: initial part of acceleration - IPA (up to 3 MeV); matching between focusing channels with different types and structures; high energy part of accelerator (HBL) with high number of focusing elements and accelerating structure.

Single-channel scheme (HILBILAC-DTL-HBL) is used in the linac as before. High acceptance of HILBILAC [5-7] and high current limit (700 mA on a frequency of 350 MHz) make possible to form beam at the IPA output with good transverse characteristics.

Use of focusing by superconducting solenoids at DTL and HBL alleviates the other problems: a)single-type focusing makes possible good matching between different linac part:(HILBILAC-DTL section and DTL-HBL section); b) changing quadruple lenses to solenoids decreases channel sensitivity to random perturbations approximately by a factor of 10 (computer simulation); c) use SSF at HBL section makes possible use of "long" cavities (10-13 m in length) based on D&W structure without subdivision on sections .Abandonment of sectionalized HBL cavities structure and coupling bridges between sections make possible essential decrease accelerating field sensitivity to geometrical errors of cavity. Requirements for evenness of "long" cavity excitation thought 7 power input from regotron reduce as well [5].

Development of such type linac indicates that DTL section realization is not improbable but there are a diversity of difficulties. The main problems are associated with high inductive coupling between solenoids, with strong ponderomotive forces and with scattering fields. Calculated characteristics of the linac are listed below:

Parameter	HILBILAC	DTL	HBL
Injection energy, MeV	0.15	3	100
Output energy, MeV	3	100	1000
Frequency, MHz	350	350	1050
Length, m	9	100	900
Beam current, mA	250	250	250
Cavity type	opposed vibrator	DTL	D&W
Number of cavities	2	7* (32**)	65*
Power transferred to beam, MW	0.7	24	255
Focusing type	SSF	SSF	SSF
Synchronous phase, grad	90-40	30	30
Channel acceptance, π cm··mrad	2.5	3	7.5
Aperture diameter (R_a), mm	10	10-20	20
R_b/R_a	0.5	0.5	0.5

* regotron excitation, ** klystron excitation

III. CW SUPERCONDUCTING PROTON LINEAR ACCELERATOR

Superconducting linear accelerator (SLA) of protons offers a number of advantages over "warm" accelerator. SLA makes possible to provide CW mode of operation with the currents up to tens mamps, reduce accelerator length at a sacrifice in accelerating rate, decrease RF power consumption and increase total efficiency of accelerator.

The following idea is the base of accelerator design. RFQ accelerator is used in IPA. The first accelerator part with output energy of 50 MeV is based on moderately short four-gap superconducting cavities with drift tubes exited on E_{010} -wave. The need for placement permanent magnet lenses between cavities demand cavities division into short parts. At the second accelerator part (HBL) elliptical-shape cavities with niobium plating are used. The number of cells in the cavity changes from 5 to 9 along the accelerator. Operational frequency was chosen moderately high for overall dimensions reduction. Odd ratio of first and second accelerator parts frequencies makes possible, when the occasion requires, simultaneous acceleration of H^+ and H^- ions. General parameters are listed below:

Prameter	Initial part	First part	Second part
Accelerating structure	RFQ	short cavities with drift tubes	9-cells cavities
Input energy, MeV	0.06	3	50*
Output energy, MeV	3	50*	1000
Frequency, MHz	425	425	1275
Focusing type		FODO (PMQ)	FODO (PMQ)
Focusing period, m	0.007-0.056	0.3-1.0	1.0-3.0
Aperture diameter, mm	5-6	15-20	30-40
Inter-electrode voltage, kV	90		
Magnetic field gradient, kG/cm		7-8	1-2
Acceleration rate, MeV/m	1	2-5	5
Accelerator length, m	3.5	20	380
Power for beam acceleration, kW	30	470	9500
Overall losses, removed by helium,W	50	500	4100
Number of cavities	1	29	304
Beam emittance, cm·mrad		0.1	0.1

*-the possibility of energy increase up to 100 MeV if under consideration.

Design of RF power supply system of SLA is connected with the decision of a number of specific problems.

With the accelerating rate of about 5 MeV/m beam will take off power about 50 kW. At the same time RF power losses in the cavity is several watts. The following requirements are imposed on Rf supply channels: provision of high stability of RF field in the cavities under significant changing of load impedance and output power of generator; possibility of continuous adjustment of field amplitude in the cavities under aging and beam load changing; stable, without unwanted oscillations, operation under high-Q multi-mode load; fast switching-off of cavities excitation when beam is lost.

The ways of these requirements realization may be determine from estimated calculation of two limiting operational mode of "generator-feeder-cavity" assembly: a) under acceleration of the beam with 10 mA nominal current; b) in the absence of acceleration.

It is presumed that for decoupling of generator from cavity circulator with forward a_f and back a_b attenuation is inserted into feeder. Feeder attenuation is a_{feed}.

On retention of nominal amplitude of accelerating field in cavity for both cases, output power of RF generator is estimated at:

$$P_{g1} = P_b \cdot 10^{(a_{feed}+a_f)/10} \qquad \text{for } I_b = 10 \text{ mA},$$

$$P_{g2} = 0.25 \cdot P_b \qquad \text{for } I_b = 0$$

Standing wave factor K_{sw} in feeder at the generator output as a function of back attenuation in circulator (for a $_{feed}$ = 0.4 db, a_f = 0.4 db) is shown below:

a_b, db	10	15	20
K_{sw}	1.76	1.37	1.19

By this means generator has to permit power varying from nominal value (with allowance made for direct losses in feeder and circulator it is estimated at 60 kW) to 15 kW. With zero current maximal voltage in feeder at the section between cavity and circulator is the same as for I_b = 10 mA and voltage in feeder at the section between circulator and generator is smaller by a factor of 2. In the case of klystron use a_b should be greater or equal 15 db. For decreasing the number of RF supply channels the scheme with excitation of 2 or 4 cavities from one powerful generator is considered as possible one.

For discussed accelerator the total power of losses by helium (cavities and power inputs) is estimated at 4000 W. According to radiation purity criteria [2] for 400 m length accelerator the additional beam losses power is 400 W. It is 10% of 4000 W. It is reasonable to set that heat flow from environment to criostat is 10% of heat release in cavities and power inputs. As this take place, total heat power abstraction is about 4800 W. The design of crio-unit consisting of several cavities placed in criostat was chosen in accordance with these requirements.

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