DEVELOPMENT OF HILBILAC FOR INITIAL PART OF ADTT ACCELERATOR

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Abstract

High-Intensity Low-Beta Ion Linear Accelerator (HILBILAC) is developed for application in initial part of CW proton accelerator for the transmutation. The accelerator uses high-efficiency compact accelerating resonator located inside a superconducting focusing solenoid. The results of calculations of the accelerator section with 3 MeV energy and 250 mA beam current are presented along with some results of experimental study. The accelerator offers good capture of injected beam to the acceleration, very low radio-frequency power loss (10 times lesser than known RFQ accelerator), and low peak electrical field in the resonator (2-3 times lesser than RFQ). HILBILAC Pulse Prototype with 1.9 MeV energy and 250 mA pulse current has been designed, the systems of the accelerator are mounted and adjusted.

1. INTRODUCTION

The accelerator under development is intended for application in an initial part of CW proton accelerator for the transmutation [1,2]. It can be used also for material study and materials treatment [5] as well as for Boron Neutron Capture Therapy [4].

According to the concepts for ADTT accelerator architecture, basic parameters of the initial part are the following: beam current - from 100 to 250 mA, operating frequency - 350 MHz or higher, particles energy - 20 MeV, it may be obtained by a few sections. Major problems are focused on the first 3-MeV section, rest sections may be similar[6].

HILBILAC meets theese requirements well. Its scheme contains compact accelerating resonator located inside a bore of superconducting focusing solenoid [3].

2. PARAMETERS OF HILBILAC SECTIONS

At present, experience in HILBILAC designing is based on the mathematic simulation of beam dynamics and resonator electrodynamics [6], the experimental investigation of proof-of-principle accelerator providing 400 mA proton beam current [7], and physical modeling with electron beam providing 5.6 A beam current (scaling to proton beam at 200 MHz) [7].

HILBILAC is capable to accelerate a 250 mA ion beam at frequences of 350 and 700 MHz starting from 100-150 keV injection energy. Separation of accelerating and focusing functions offers a possibility to optimize beam dynamics for obtaining of near to 100% capture efficiency, small diameter and emittance of the beam. Besides, radio-frequency (RF) accelerating structures with high efficiency can be used in the HILBILAC.

In Table 1, calculated parameters of two versions of CW accelerator having 350 and 700 MHz are presented. The 700-MHz version provides filling all RF buckets in the high-energy linac, thus minimizing the charge per bunch and beam losses.

Table 1. HILBILAC sections parameters

Section	CW vers. 1	CW vers. 2	HPP
Frequency (MHz)	350	700	350
Beam current (mA)	250	250	250
Output energy (MeV)	3	3	1.9
Injection energy (MeV)	0.1	0.15	0.1
Accelerator length (m)	3	2.8	1.7
Magnetic field (T)	7	7	7
Beam diameter (mm)	3	3	3
RF power supply (kW)	770	750	475

Since designing of high-intensity CW accelerator poses a few problems, the HILBILAC Pulse Prototype (HPP) has been designed and now is mounted at MRTI. Its parameters also are presented in Table 1.

3. BEAM DYNAMICS

Beam matching between ion injector and accelerating resonator is a problem because injector-resonator distance is large in order to reduse edge magnetic field of superconducting solenoid in the ion source. In the HPP, beam transport channel with two lenses is used. Distribution of the magnetic field is shown on fig. 1 along with variation of beam radius. In the resonator, the beam has 0.15 cm radius and 0.014 cm rms deviation of radius.

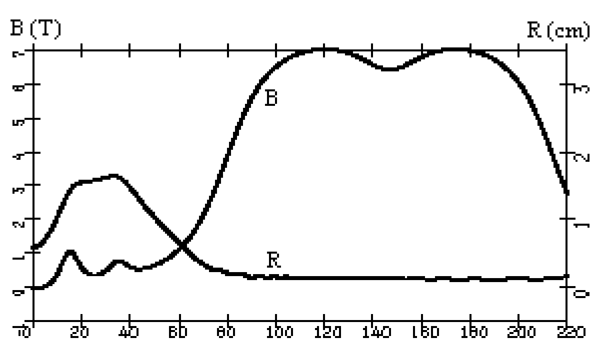

Fig. 1. Magnetic field B and beam radius R in HPP

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To achieve good beam matching and high capture efficiency, adiabatic RF bunching of the beam in rising field is used. Within initial part, the equilibrium phase decreases gradually while accelerating field increases (fig. 2). Major acceleration is made within last part of the accelerator, with acceleration rate of 2.6 MeV/m.

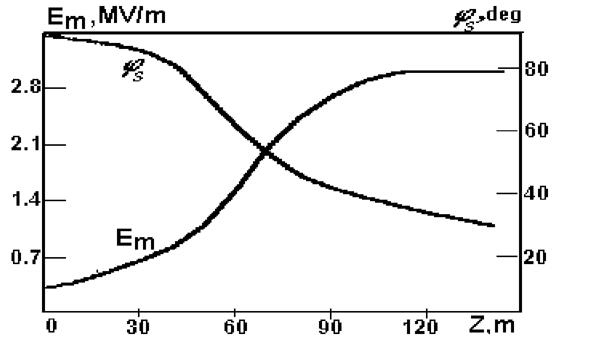

Fig. 2. Accelerating field and equilibrium phase in HPP

On fig. 3 is shown energy spectrum of accelerated beam. Almost all particles lie within 1.8-2 MeV energy range except about 2% that are unaccelerated.

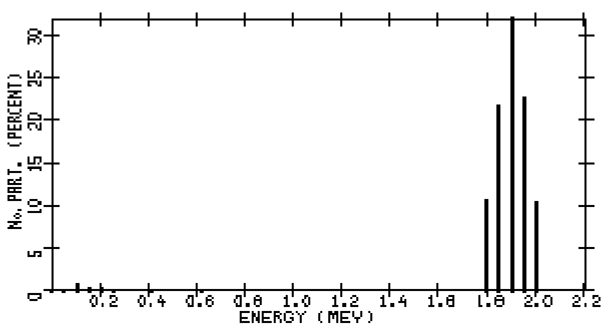

Fig. 3. Energy spectrum of accelerated beam in HPP

4. HILBILAC PULSE PROTOTYPE DESIGN

The ion injector (fig.4, ref.1) uses ion source duoplasmatron type. The transport channel (ref.2) includes two magnetic lenses. Owing to use of magnetic screens and compensating coil, edge magnetic field of the focusing solenoid in the source is under 0.001 T.

The cryostat (ref. 3) includes vacuum envelope, helium vessel for superconducting solenoid and two thermal shields. The superconducting solenoid (ref. 5) has 4.2 K temperature and uses NbTi cables. Magnetic field of 7.9 T was obtained on the tests of the solenoid.

The accelerating resonator (ref. 4) is placed in "warm" cryostat bore. Two coaxial feeders (ref. 6) are used to supply RF power from two output RF amplifiers based on GI-51A vacuum tubes each providing 300 kW pulse RF power.

The beam diagnostic system includes beam profile meter, foil transducer for energy spectrum measurement (ref. 7) and beam emittance meter (ref. 8).

At present, all systems of the HPP have been designed, the systems are manufactured and mounted.

5. ACCELERATING RESONATOR

The resonator has longitudinal RF magnetic field (H-resonator). It consists of cavity, two vanes, a number of drift tubes alternatively connected to the vanes thus forming accelerating gaps (fig. 5). The cavity has hexagonal cross-section with width gradually rising along the resonator. The ends of the vanes are braced to obtain required field distribution. Every drift tube is a thin ring. The stems are of conic shape providing good removal of heat from the drift tubes to the vanes.

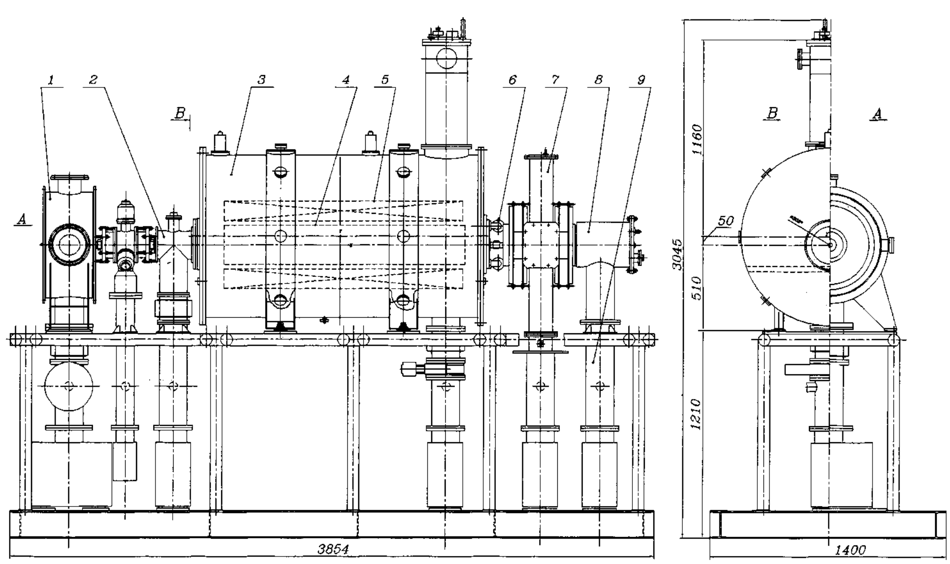

Fig. 4. HILBILAC Pulse Prototype design

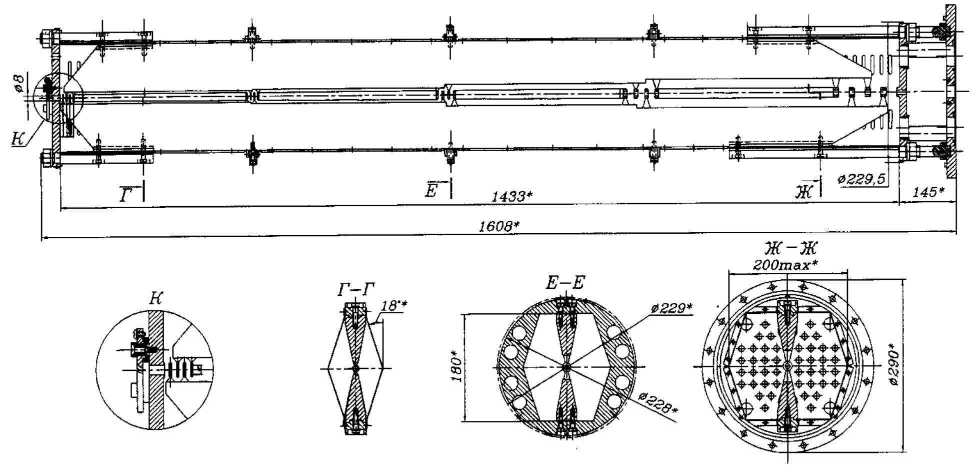

Fig. 5. HILBILAC Pulse Prototype resonator design

The resonator parameters were calculated using 2D REAL and GNOM codes based on the mesh technique. The parameters were checked with RF modeling. In particular, full-scale RF model of HPP resonator was manufactured and tested, field distribution shown on fig. 2 was obtained.

Effective shunt impedance of the resonator vs relative velocity of particles is given on fig. 6. The dots indicate values measured with RF models at 200-300 MHz and scaled to 350 MHz. Measured values are 65-75% of calculated values. The shunt impedance of the structure is very high.

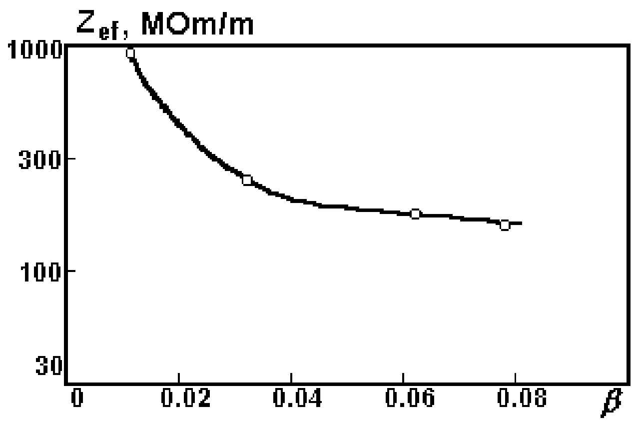

Fig. 6. Measured shunt impedance of the resonator

Table 2. Parameters of the accelerating resonators

Section	CW	HPP
Frequency (MHz)	350	350
Length (m)	2.83	1.43
Number of gaps	215	141
Cavity width (mm)	100-210	92-200
Accelerating field (MV/m)	0.26-2.4	0.26-3
Pick surface field (MV/m)	11	14.7
RF power loss (kW)	42	23
Efficiency	95%	95%

Design of the resonator is well suitable for the technique developed in GRUMMAN and used for BEAR and CWDD [8]. For CW accelerator, the cavity and vanes may be manufactured from TeCu alloy combining high conductivity with good mechanical properties, and electroformed with pure Cu. The design offers good thermal characteristics: local power dissipation does not exceed 10 W/cm^2 and overheating of elements does not exceed 10°.

6. CONCLUSION

A comparison of HILBILAC and well-known RFQ accelerator in indicated range of parameters shows the following. HILBILAC offers much more limit current of ion beam providing acceleration of 250-mA beam at any frequency without beam funneling. RF power loss in HILBILAC is about 10 times lesser, that gives an economy in RF power and makes more simple the solution of heat removal problem. Peak surface field in HILBILAC is 2-3 times lesser, that ensures more reliable operation. Pay for theese merits is necessity to use the superconducting solenoid.

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