Scheme and Parameters of a 250-mA, 20 MeV CW Proton Accelerator*

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Abstract

Results of a configuration design trade study for a 250 mA, 20 MeV proton accelerator are presented. The accelerator design is based on High Intensity Low Beta Ion Linac (HILBILAC) with superconducting solenoid beam focusing. Two variants of the accelerator are analyzed. The first includes a HILBILAC section with output energy of 3 MeV and a number of DTL sections with quadrupole focusing. The second consists completely of HILBILAC sections. The main features of a HILBILAC based system are: absence of beam funneling, use of high operating frequency for acceleration of low emittance beam, high accelerating resonator efficiency.

1. INTRODUCTION

The accelerator under development is designed for application in an initial part of the cw proton accelerator which can be used for intense neutron source intended for accelerator based conversion (ABC) of surplus plutonium to energy [1]. A feature of the accelerator is a combination of high beam current (25O mA) and small value of transverse normalized rms emittance (1.2 mm·mrad).

Basic requirements for the initial part are the following: absence of beam funneling scheme due to its complexity and increase of beam emittance; use of high operating frequency for low emittance beam acceleration; minimal beam losses determined by thermal factors up to the energy of about 10 MeV, and by radiation safety of the accelerator above the energy of 10 MeV; possibility combining the accelerator at the energy of 20 MeV with 700 MHz Bridge Coupled DTL (BCDTL) [2] which will be used in subsequent part of the ABC accelerator.

A high current accelerator scheme based on HILBILAC (High Intensity Low Beta Ion Linac) had been earlier proposed [3]. A HILBILAC section includes a resonator located inside a bore of superconducting focusing solenoid. The acceleration method has been tested on SIU-1 pulsed proton accelerator where the record value of beam current (400 mA) for RF ion accelerators was obtained [4].

HILBILAC basic feature is the following parameter combination in one accelerator. First, as calculations show, accelerators of the type are capable of accelerating beam currents up to 15 A [5]. Due to high values of the beam current limit, HILBILAC is capable of accelerating (at a frequency of 350 MHz) a 250 mA proton beam with a considerable margin with regard to limiting current. Separation of focusing and acceleration in HILBILAC allows to optimize beam dynamics for providing a capture efficiency close to 100 % [6]. HILBILAC allows to use the injection energy of 75 - 150 keV for acceleration of a 250 mA proton beam. High values of accelerating and focusing fields enable the beam with diameter of about 3 mm to be accelerated thus providing the low value of beam emittance. Use of adiabatic bunching in HILBILAC allows to form the bunch with a small longitudinal phase volume (about 1 MeV·deg for the energy of 3 MeV). And finally, accelerating structures with high effective shunt impedance (up to 200 MΩ / m at 350 MHz in low energy part) can be used in HILBILAC.

2.GENERAL DESIGN CONSIDERATIONS

Earlier studied HILBILAC accelerators were intended for beam energy of 1.5-5 MeV. The studies were mainly oriented to achieve high current beam values. The problem of obtaining low emittance beam in HILBILAC was not investigated. A new problem is also combining HILBILAC sections with each other or with other accelerator types. Therefore, the main attention is taken to solving the problems. In the course of conceptual design study the following things were used: experience of calculations, design and experiments of SIU-1 accelerator [4], results of analytical and numerical simulations both of adiabatic beam bunching [6] and accelerating channel [7,8], 2D LIDOS beam dynamics code [9], 3D BEAMPATH beam dynamics code [10], 2D GNOM and REAL electro-dynamics codes [8], cold model electrodynamics measurements [11]. The beam dynamics problems are mainly define ones in the stage of study: careful beam matching along beamline, beam acceleration with minimal emittance growth, halo formation and high capture efficiency.

The low energy part is the key element to solve the problems. The series of beam dynamics simulations have been conducted with 3D BEAMPATH code. Various variants of both beam model and HILBILAC parameters have been studied. The number of "big particles" was varied from 1000 to 8000 in the computations. The initial beam

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phase distributions were KV and Gaussians ones. Dipole component of accelerating field have been taken into account. Several variants of distributions for accelerating and focusing fields were investigated. The study shows that to achieve beam matching and high capture efficiency it is expedient to use adiabatic beam bunching in rising accelerating field [6]. A small value of transverse Coulomb parameter of the beam is desirable to have a small emittance growth. Main parameters for one of the variants are given below: injection energy is 150 keV, output energy is 3 MeV, beam current is 250 mA, operating frequency is 352 MHz, maximum accelerating wave amplitude and surface electric field are 2.4 MV/m and 9.0 MV/m respectively. The rms emittance variations along the section are given in Fig. 1.

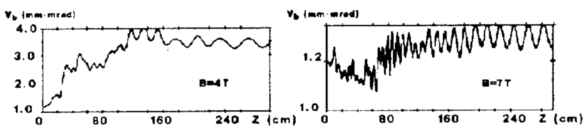

Fig.1. rms emittance variations along HILBILAC section

The figure indicates it is necessary to use high value of focusing field to accelerate a beam with minimal emittance growth. The high value of magnetic field allows also to reduce influence of phase oscillation frequencies dispersion along the beam bunch on transverse beam matching. For the variant the capture efficiency is about of 85% but main beam losses are distributed along the buncher beginning where the beam energy is 150 keV. The beam with minimal halo is formed at the section for 7 T magnetic field (Fig. 2).

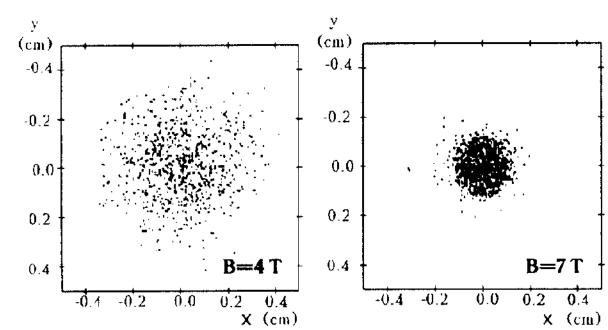

Fig.2. Cross sections of the beam at HILBILAC section

At present it is expedient to consider two versions of the 250 mA, 20 MeV accelerator. The first incorporates a HILBILAC section up to the energy of 3 MeV with further acceleration of the beam in DTL and focusing by permanent magnet quadrupoles (PMQ). The advantage of the approach consists in the proved feasibility of both HILBILAC and DTL accelerators (in pulsed mode). Its drawback is associated with doubts regarding the DTL applicability (with the PMQs) at the energies above 10 MeV due to the radiation resistivity of PMQ. The second version consists of a few HILBILAC sections with acceleration up to the energy of 20 MeV .

3.HILBILAC-DTL INITIAL PART

The accelerator includes one HILBILAC and six DTL sections. The sections operate at a frequency of 352 MHz. Matching devices are installed between DTL and HILBILAC, as well as between BCDTL and DTL to provide beam transport with no losses. Number and length of the sections were chosen to meet the requirement that excitation of one section should be realized by single RF generator with power of 1.0 MW. YK-1350 cw klystron of Philips could be used for the RF power system.

Beam focusing is realized by means of the FOFODODO focusing structure to decrease required gradients of magnetic lenses compared with the conventional FODO structure. Basic parameters of DTL sections are the following: length of resonators is 1.52-1.70 m, accelerating wave amplitude is 2.1 MV/m, gradients of focusing field are 20-70 T/m, RF losses per resonator are 0.14-0.16 MW, accelerating resonator efficiency is 82-83%.

The schematic view of a beam matching section between HILBILAC and DTL is shown in Fig. 3. The section contains six quadrupole lenses for transverse beam matching and two 352 MHz bunchers for longitudinal one.

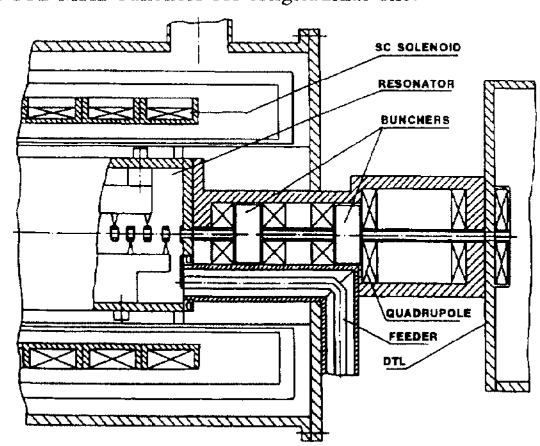

Fig.3. HILBILAC - DTL beam matching section

Parameters of the matching section are the following: length of matching section is 0.5 m, lens lengths are 20 - 30 mm, peak field gradient in lens is 200 T / m, buncher length is 50 mm, electrical field in buncher 4 MV/m. The matching section is located inside a magnetic screen for protection of the section from magnetic field of HILBILAC. LIDOS beam dynamics calculations show that a mismatching factor is equal to 1.6 for beam current of 250 mA and real magnetic field of the focusing solenoid. The effect of beam Coulomb repulsion upon the mismatching factor is much stronger than that of the magnetic field under the conditions of chosen screening method. The similar computations for a DTL-BCDTL beam matching section consisting of four quadrupoles along a distance of 0.4 m show that the mismatching factor is 1.1 for low beam current and about 1.2 for 250 mA.

4. HILBILAC BASED INITIAL PART

Second variant of the initial part represents seven 352 MHz HILBILAC sections operating up to the energy of 20 MeV (Fig. 4). The accelerating resonators can represent in the case a continuous chain with no gaps, and no devices are required for longitudinal beam matching. Gaps between solenoids (150 mm as a minimum) are necessary for supply of RF power and cooling water. Calculations demonstrate that if solenoids with such gaps are used, crevasses in a focusing magnetic field amount to 30 %, and the crevasses result in intolerable beam mismatching. To exclude the crevasses, solenoids with a special form of compensating coils can be used. A good beam matching can be obtained through selection of the compensating coil dimensions and the beam envelope has practically no oscillations. Parameters of the variant are given below: injection energy is 0.15 MeV, initial part length is 14 m, cryostate diameter is 0.7 - 1 m, magnetic induction of focusing field is 5-7 T.

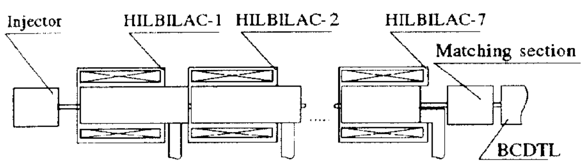

Fig. 4. Scheme of HILBILAC based initial part

The two chamber H-resonator [8,11] can be used as accelerating resonators for all the sections. Shunt impedance for the resonators decreases with increasing velocity of particles. Therefore, both accelerating wave amplitude (1.5 MV/m) and synchronous phase (30°) for the last resonators are smaller then those in the previous ones. The values are sufficient for longitudinal support of the bunches in all resonators. Estimations shows that RF losses are 50 kW for the first resonator and 150 kW for the last when accelerating wave amplitude is varied from 2.4 MV/m to 1.5 MV/m along the initial part. Length of the first resonator is 2.85 m and changes further from 1.55 m to 2.1 m.

5. HILBILAC-TEST ACCELERATOR

Because of both the unique nature and high cost of the cw accelerator development, it is expedient to test and work out basic scientific and engineering approaches by means of a pulsed accelerator HILBILAC-TEST.

The HILBILAC-TEST parameters are selected to be as close as possible to the parameters of cw HILBILAC. Beam current (250 mA), operating frequency (352 MHz), magnetic induction (5-7 T), accelerating resonator efficiency (94%) are the same as in cw HILBILAC. Accelerating wave amplitude (3 MV/m) and injection energy (0.1 MeV) are higher and lower respectively than in the cw HILBILAC because of limitation on an accelerator resonator length (1.24 m). This enabled not only the bunching but the beam acceleration (to 1.5 MeV) to be obtained as well. RF power supply is 37O kW. Equipment earlier developed and manufactured for SIU-2 accelerator [4], can be used for constructing HILBILAC-TEST. The accelerator will operate with beam pulse duration of 100-300 μsec and repetition rate of 1 pulse/sec. During of our experiments with SIU-1 accelerator, the value of 4 MV/m had been obtained for accelerating wave amplitude [5]. Thus, there exists a fairly good evidence that HILBILAC-TEST accelerator will operate reliably.

6. CONCLUSION

Above listed parameters have a preliminary character and serve as an examples of feasibility of cw accelerators based on HILBILAC. Careful study and optimization of beam injection, H-resonator electrodynamics, profiles of RF losses and temperatures are needed to accomplish the project along with HILBILAC - TEST experiments.

7. REFERENCES

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