The Beijing 35 MeV Proton Linac

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Summary

The Beijing 35 MeV Proton Linac is described in design feature and techniques with emphasis on the 10 MeV to 35 MeV energy extension. Field distribution adjustments, accelerator tune-up and the status are also presented in this paper.

Introduction

The Beijing Proton Linac has been extended from 10 MeV to 35 MeV, devoted to the short-lived medical isotope production, fast neutron therapy study and nuclear experiments.

The first 10 MeV beam was produced at the end of 1982[1], and operational tests continued until installation of the 35 MeV linac in 1984. This upgraded Linac came into operation in August 1985. At the end of 1986, installation and adjustment of the application transport system were completed, and proton beams were delivered to two target stations with gratifying performance. In 1987 and 1988, some short-lived medical isotopes, such as ^{201}Tl, ^{11}C and ^{67}Ga were produced by 35 MeV proton bombardment of natural materials.

General Description

Fig. 1 shows the general layout of the Beijing 35 MeV Proton Linac Facility. The Linac complex is essentially composed of 750 keV Cockcroft Walton injector, 35 MeV drift tube linac and 35 MeV application beam transport system.

The 35 MeV proton beam passing through a length of common transport line, via the bending magnets, the isotope production transport line and the neutron therapy transport line, reaches the target rooms which can be seen at the lower left and the upper left of Fig. 1. A beam measurement line is located at the end of the tunnel. In the layout of the Linac building, space is preserved in the tunnel for eventual future energy extension to 70 MeV.

Design Feature and Techniques of the 35 MeV Linac

Design work of the 10 MeV to 35 MeV energy extension has proved rather extraordinary. It was done according to specific circumstances and requirements as follows:

1. Modification of the 10 MeV Linac structure should be limited as much as possible, in order to possess the forthcoming experience in machine construction, installation and beam tests.

2. Potentiality of the existing equipment should be brought into full play, in order to minimize the cost for the energy extension project. The major potential equipment has been the rf power system with an output of 5 MW. In the 10 MeV Linac, a pulse power of 1.5 MW is adequate for a 60 mA beam. Thus, there would be some 3.5 MW of rf power remained. And it should be utilized to achieve a proton beam with appropriate energy and intensity fulfilling the requirements for the mentioned medical applications.

3. Rf power should be supplied to the accelerating tank via two symmetrical feed ports, in order to reduce the phase variation along the tank and to suppress the TM011 and TM012 modes. The feed ports should be at 1/4 and 3/4 points along the tank length. By reason of 1., to remachine a new feed port on the existing 10 MeV tank is not allowable.

4. The length of the extended accelerating tank will be more than 20 m. Thus, the axial distribution of accelerating field should be designed so that possible difficulties in tuning up such a long tank can be eased up somewhat.

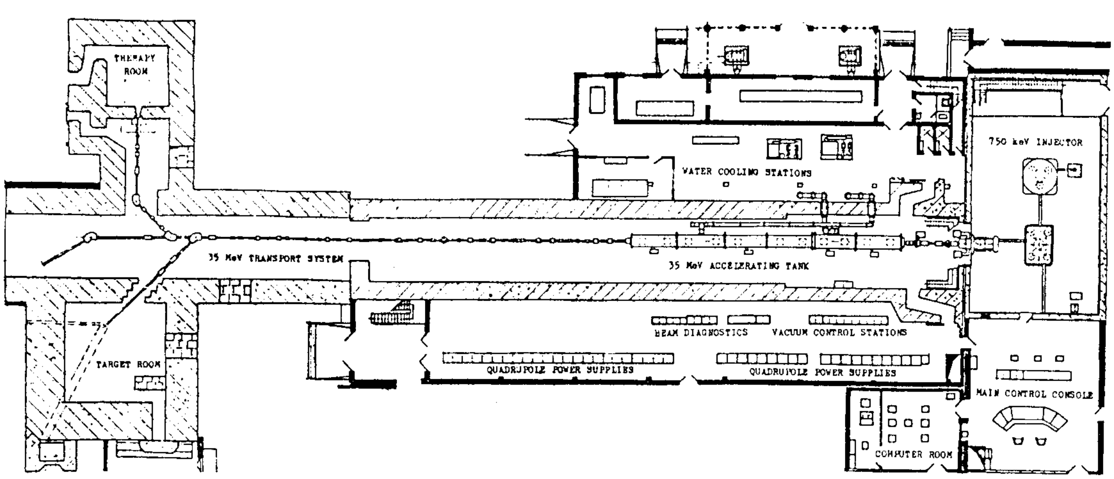

Figure 1: General layout of the Beijing Proton Linac Facility

In order to meet above requirements simultaneously, an unique design procedure was finally chosen as follows:

1. The dowstream feed port of the original 10 MeV tank is adopted as the upstream feed port of the extended 35 MeV tank. The axial distance of this adopted feed port to the tank input is known as $l_1 = 5.5\ m$. It is reasoned that the total length of the tank to be extended will be about $4l_1 = 22\ m$. By such a choice, the requirements 1. and 3. are satisfied.

2. Assuming the extended tank length of 22 m and the allowable maximum accelerating field of 2.6 MV/m, the output energy of a 60 mA proton beam driven by 5 MW rf power is found about 35 MeV. With such a beam energy, the Linac meets the requirement in producing the medical short-lived isotopes ^{201}Tl, ^{67}Ga and ^{11}C etc. The requirements in fast neutron therapy study can also be satisfied basically. Fast neutrons around 20 MeV (average energy) can be obtained by bombardment of the 35 MeV proton beam on beryllium target. The neutron absorbed dose rate will be 145 rad/min, at 1 m from the target, in the 0° direction of the beam[2].

3. The field distribution in the accelerating tank follows a linear increasing law as:

$$E_o = E_{oi} + Cz \qquad (1)$$

where E_{oi} is the average axial field at the tank entrance, C is the field tilting rate. In the original 10 MeV tank, E_{oi} is 1.55 MV/m, C is 0.075 MV/m^2, and the average axial field at its exit is 2.08 MV/m. If the original values of E_{oi} and C are followed, the average axial field at the exit of the 22 m, 35 MeV tank would exceed 3 MV/m. At such a high field, reliable operation of the Linac would not be certain. More importantly, there would be difficulty in field tilt tuning as well by choosing such a steep tilting rate of 0.075 MV/m^2. With the geometry of the drift tubes and their axial locations unchanged in the first 10 MeV portion, while ensuring a reasonable field tilting rate in the long 35 MeV tank, E_{oi} and C are chosen to be 1.65 MV/m and 0.044 MV/m^2 respectively, and the exit field arrives at 2.6 MV/m. Fig. 2 shows the average axial field distribution in the original 10 MeV tank and the extended 35 MeV tank. In the first 10 MeV portion, were the energy gain of each cell kept constant, the sychronous phase angle would have to conform to

$$\varphi_s = arcos\left(\frac{dW/dz}{eTE_o}\right) \qquad (2)$$

where dW/dz is the rate of energy gain, T is the transit time factor. Specifically, dW/dz and T are the parameters of the original 10 MeV tank, while E_o is the field distributing values of the 35 MeV tank. Accordingly, the synchronous phase angle varies gradually from -40° to -25° along the first 10 MeV portion. The width of longitudinal stable region provided by such a sychronous phase angle is acceptable for capturing even a proton beam of 100 mA. Thus, the phase angle is kept to be a constant value of -25° through the extended portion.

4. Two different accelerating cavity diameters and two different drift tube diameters are chosen in the 35 MeV Linac geometry. The cavity and drift tube diameters in the first 10 MeV portion are Ø 949.4 mm and Ø 180 mm, while those in the 10 to 35 Mev portion are chosen to be Ø 909 mm and Ø 160 mm respectively. By such a choice, higher shunt impedance, higher transit time factor and consequent higher structure efficiency thus are maintained along the prolonged tank.

5. The LASL post couplers are used with periodicity one per two drift tubes for field stabilisation against beam loading and detuning effects in such a long tank.

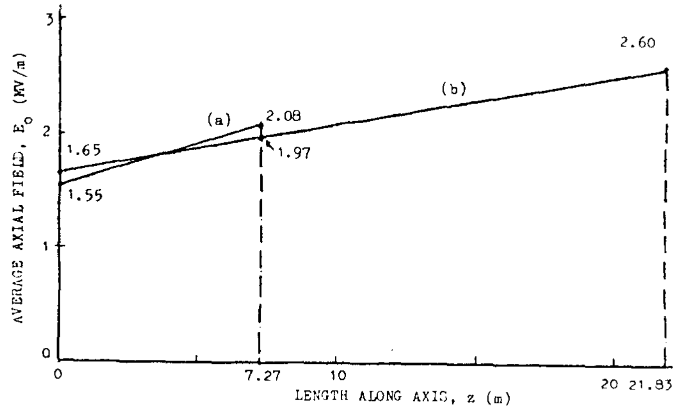

Figure 2: Average axial field distribution
(a) in the original 10 MeV tank
(b) in the extended 35 MeV tank

6. Finally, according to the structure and parameters considered above, exact calculations of the Linac geometry and dynamics parameters were accomplished by using the programs LAC, LAD and LAM[3]. The main parameters evaluated are listed in Table I.

Table I
Design Parameters of the Linac

Input Energy	(MeV)	0.75
Output Energy	(MeV)	35.51
Peak Current	(mA)	60
Beam Pulse Length	(μ s)	50 100
Repétition Rate	(pps)	1,2,5,12,5
Momentum Spread	(%)	±0.6
Normalized Emittance	($\pi \cdot mm \cdot mrad$)	6-8 (90%)
Frequency	**(MHz)**	**201.25**
Cavity length	(m)	21.83
Average Axial Field	(MV/m)	1.65-2.60
Synchronous Phase	(°)	-40 − -25
Cavity Diameter	(mm)	949.4, 909.0
Drift Tube Diameter	(mm)	180, 160
Number of Cells		104
Number of Drift Tubes		103 + 2 x 1/2
Number of Post Couplers		52
Cavity Excitation Power	(MW)	2.8
Total Power for 60 mA	(MW)	4.89
Quadrupole Gradient	(kG/cm)	9.2–2.0
Number of Quadrupoles		105

Field Adjustments and Accelerator Tune-up

Axial Field Tilting and Stabilization

Due to single cavity of 104 cells, 22 meters in length and some existing drawbacks in the cavity structure, the field tilting and stabilization turned out to be a laborious task.

Some of the major existing drawbacks are:

1. There is a structural discontinuity in the transition section wherein the tank and drift tube diameters change abruptly. The axial field at that transition region will be perturbed harmfully.

2. The cell length varies from 60.36 mm to 396.44 mm, exhibiting severe nonperiodicity in the accelerating structure. Selecting the post diameter of 25 mm throughout is unlikely to be favorable in the field stabilization.

3. There are only five tuners distributing along the extended sections. They are not enough for the field perturbation.

To overcome above-mentioned shortcomings, some effective measures were taken. Firstly, at the structural discontinuity and positions where the field distribution displaying large humps, short tuning bars were added to the tank wall in addition to the regular ones. The amount of bulk tuning was determined experimentally to set the field roughly to correct tilt. Secondly, post couplers were arranged in groups with excentric tabs of three different sizes, and set to different insertions systematically from group to group to obtain stabilized field.

Perturbation measurements were performed throughout the field adjusting process. Field distribution was then brought to a correct tilt by adjusting the half drift tube lengths at both ends of the tank. Several excessive humps on the field distribution were cured by setting additional trimming bulks at some effective locations. Satifactory and stabilization of the average axial field were achieved by adjusting the insertion of the piston tuners and post couplers, and the orientation of the excentric tabs on the posts.

The average axial field distribution obtained in the 35 MeV tank is shown in Fig. 3[4]. Compared with the theoretical values, field deviations found in a few cells are up to 10.5 %, while that in 80 % and more cells are less than 3 %, and the root mean square deviation for that of all is 3.15 %. With the posts properly adjusted, the frequency separation between the operating mode (TM010) and the nearest higher mode (TM011) was found to be 179 kHz. It was larger than that of 74 kHz in the unstabilized case by a factor of 2.4.

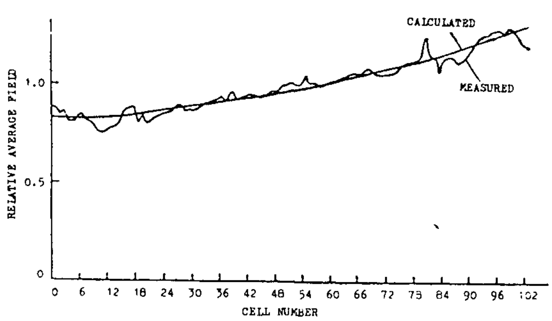

Figure 3: Average axial field distribution in the 35 MeV tank

Beam Test of the Accelerating Cavity

The purpose of beam test is to optimize the operating parameters of the accelerating cavity, so that the beam intensity and energy of the accelerator fulfil its design specifications. The theoretical parameters prepared for the accelerator tune-up are obtained by calculation of the beam matching program LAM, under the condition of a lossless transmission simulated by the multipartical program, based on the beam dynamics.

With these parameters, the first beam of the 35 MeV Linac was extracted in August 1985, with an output intensity of 3.2 mA and an energy of 34.5 MeV. Later, by trimming the quadrupole current individually, and adjusting the tank excitation power to a proper level, optimum tune-up parameters have found for the machine operation. In November, maximum output intensity of 70 mA at an energy of 35.6 MeV has obtained. And momentum spread of the beam at 25 mA was found $\leq \pm 0.43$ %, using an analyzing magnet and a multiwire target. With a single buncher, transmission through the accelerator was found 60 % and more.

Beam Test of the 35 MeV Transport System

The general layout of the 35 MeV application beam transport system can be seen at the left part of Fig. 1. The system consists of a common line (35.32 m), an isotope production line (9.89 m), a neutron therapy line (12.64 m) and a measurement line (8.64 m). There are 27 quadrupoles, 3 bending magnets, 1 analyzing magnet, 8 steering coils and various beam measurement devices.

Tune-up of the 35 MeV transport system has performed using direct search method. The whole system came into operation in December 1986. Transmission properties obtained during initial tune-up were: 88 % for the isotope production line, 93 % for the neutron therapy line, both exceed the predicted values.

Project Status

The Beijing 35 MeV Proton Linac has been operating intermittently for one year in connection with some tests on subsystems. Reproducibility and reliability of the machine are improving. At present, tuning of some subsystems is accessible only at the substations. The controlling and monitoring of the facility are concentrated at the main control console. For the purpose, improvement of the hardware and software for the PDP-11/34 computer were done.

Installation of the medical isotope production facility, consisting of working boxes, target systems, manipulaters and local control system, is completed mostly. Trial production of the short-lived medical isotope ^{201}Tl, ^{67}Ga, ^{11}C and ^{57}Co were performed with the 35 MeV proton beam. The quality of these products have tested excellent. The fast neutron therapy facility components are being installed. Those are: the target system, transmission ionization chambers, secondary collimator, therapy chair and control system, etc. Research work in this area will begin next year.

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