STATUS OF THE BEIJING PROTON LINAC

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Introduction

The Beijing Proton Linac(BPL) was planned as an injector for Beijing Proton Synchrotron (BPS) which was to be the central facility in a proposed high energy physics experimental center.[1,2] Design work for BPL was started from Aug. 1978. Contracts with industry were made from 1979. Manufacture and delivery of most major components for the 750 KeV preinjector and the first 10 MeV tank were proceeded according to schedule.

In 1980, the ambitious BPS project had to be abandoned because of financial constraints, and a decision was made to utilize the BPL for some medical applications. Thus a BPL conversion project was generated accordingly. Construction of the converted BPL has been in two phases. First, the 750 KeV injector and the 10 MeV linac section were installed and tested. The first 10MeV beam of 14mA (without buncher) was produced at the end of 1982. The record current was 120mA at 0.2% duty in 1984. Second, additions for the 35MeV linac will be installed and put into operation. This task is scheduled for completion in 1985.

General Description

Fig. 1 shows the equipment layout of BPL. The linac system is essentially composed of a 750KeV Cockcroft-Walton injector and a 10(35)MeV drift tube linac.

The injector is housed in a Faraday cage at the right side of Fig.1. Its audio power generator and stabilizer are installed in the basement rooms nearby. The linac tank and the 750KeV transport line are housed in a concrete tunnel surrounded by equipment galleries where quadrupole power supplies, vacuum stations, beam diagnostics, water cooling stations and radio frequency power sources are installed. The radio frequency system is installed in the equipment hall on the second floor, it is not shown in this figure.

The main control room and its associated computer room are in the lower right corner of Fig.1. The shaded parts on the diagram denote the additions for 35 MeV linac system which will be discussed later. Fig.2 shows the photograph of the 10 MeV linac.

The design parameters of the linac are given in Table I. The design specifications of the 35MeV linac are listed along with those of the 10MeV linac in Table II.

TABLE I

DESIGN PERFORMANCE PARAMETERS

Injector Energy	(MeV)	0.75
Output Energy	(MeV)	9.68(35.51)
Beam Current	(mA)	60-80
Beam Pulse Length	(μs)	50-150
Operating Frequency	(MHz)	201.25
R.F.Pulse Length	(μs)	300-500
Pulse Repetition Rate	(pps)	1,2,5,12.5
Normalized Emittance	(πmm.mrad)	6-8
Output Momentum Spread	(%)	±0.6

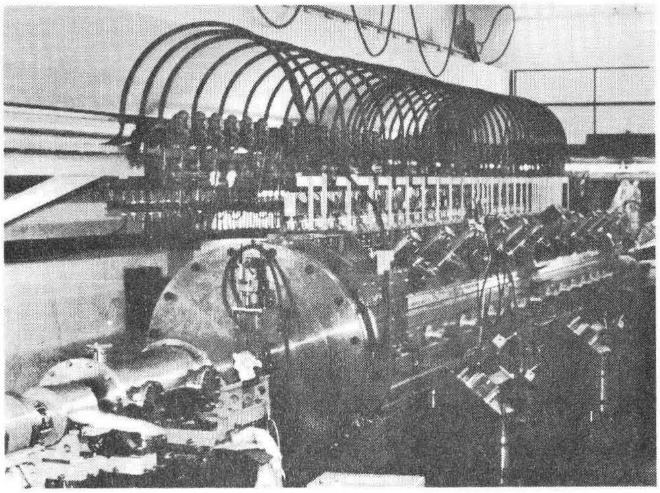

Fig.2 The 10 MeV Linac

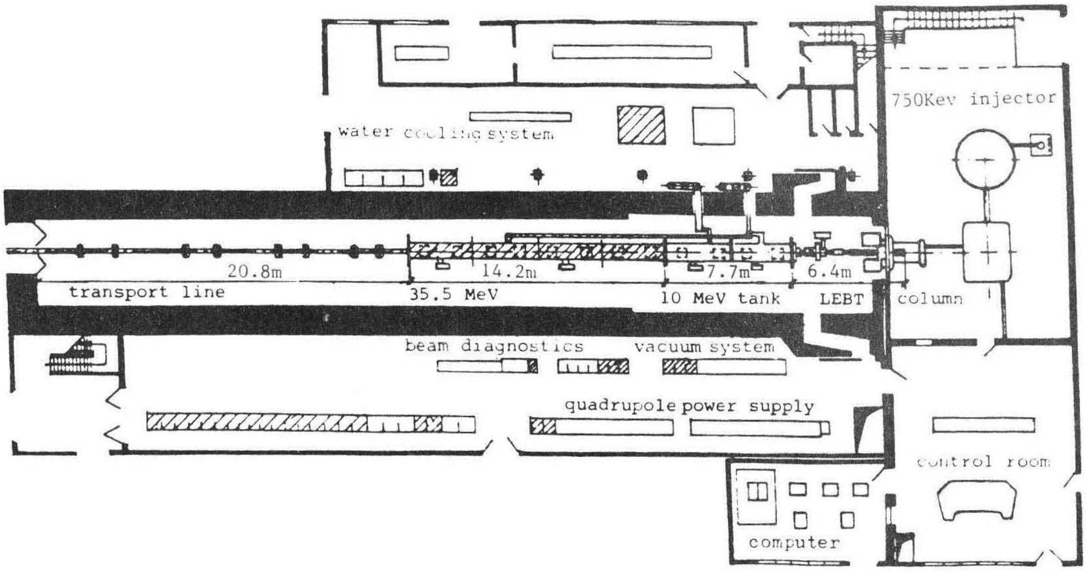

Fig.1 General Layout of BPL

TABLE II

DESIGN SPECIFICATIONS

		10MeV	35MeV
Proton Energy In	(MeV)	0.75	0.75
Proton Energy Out	(MeV)	9.68	35.51
Cavity Length	(m)	7.27	21.83
Cavity Diameter	(mm)	949.4	949.4,909.0
Drift Tube Diameter	(mm)	180	180,160
Bore Hole Diameter	(mm)	20,25	20,25,30
Average Axial Field	(MV/m)	1.55-2.08	1.65-2.6
Axial Transit Factor		0.67-0.81	0.67-0.82
Syn. Phase Angle	(Deg.)	-35- -30.3	-40- -25
Eff. Shunt Imped.	(MΩ/m)	29.5-47.8	29.5-45.96
Peak Surface Field	(MV/m)	8.3-9.5	9.13-12.58
Average Gap Field	(MV/m)	7.15-6.79	7.6-8.5
Number of Cells		56	104
Number of Full D.T.		55	103
Number of Half D.T.		2	2
Number of Post Couplers		28	52
Excitation Power	(MW)	0.5	1.88
Total Power for 80mA	(MW)	1.2	4.66

Operation of the 10 MeV Linac

The first part of BPL (a 10MeV linac) came into operation, along with its 750KeV Cockcroft-Walton injector, on Dec. 1982. Since that time, efforts have been made to clear up troubles arising from various systems during tune-up of the machine, and to optimize beam properties to realize the design parameters.[4,5,6]

Injector

The injector has a high gradient double gap accelerating column based on the design of the CERN 750KeV unit. Its mean accelerating gradient have decreased from 58KV/cm across 12.9cm gap of the CERN design to 30KV/cm across 25cm gap. It was hoped that more reliable operation would be assured at this lower gradient. However, frequent voltage breakdown of the column at 750KV has been a teething problem in the injector area.

During initial tests of the injector, it was found that the column could not hold at 750KV more than 4 hours after a lengthy conditioning process. After successive breakdowns, the column could stand up to 680KV at most, unless another run of conditioning process was executed properly.

In order to speed up conditioning process, and to improve voltage holding property, a measure of charging the column with inert gas has been taken.[7] Nitrogen was tried first. The column could be conditioned up to 750KV in less than 3 hours, but would breakdown when proton beam was being accelerated. Following unsuccessful attempt of using nitrogen, hydrogen was tried next. By setting the gas pressure around (1-3) x 10^{-4} torr, it was possible to make the column operational at 750KV without excessive breakdowns.

There is a drawback, however, existing in this mode of operation. Beam intensity read at the column exit is much higher than that normally extracted from the ion source. As a consequence, a poor transmission in the LEBT has been observed. More recently, two measures have been taken to improve the vacuum system. Pump oil of the silicone type is used in place of the normal pump oil. A super-pure hydrogen generator is used in place of the ordinary gas holder. Both measures have proved to be effective in reducing the number of breakdowns.

In the last few months, it was found that gas pressure could be lowered properly without deteriorating the operational behavior of the column. Thus an effective process of run-up the column is performed as follows.

1. At the beginning, the column is charged to about 1.5x10^{-4} torr, and the high voltage can be raised up to 750KV within a few minutes.

2. During the course of conditioning, hydrogen flow is being reduced gradually, and can be turned off completely within 3 hours.

At present, the breakdown rate at 750KV lies from 100 to 300 per week when the relative humidity is kept within 40% to 50%.

There are items still to be debugged in the injector area. Those are the control system, bouncer and ion source power supply.

Low Energy Beam Transport

Tune-up of the LEBT is performed by observing the intensity readings from six beam current transformers, while adjusting the currents of four quadrupole triplets and five quadrupole singlets successively for maximum transmission through the line. The adjustment is made around the theoretical current settings which were computed by assumed emittance at the entrance to the LEBT.

The reproducibility of the LEBT performance has been discouraging. It is necessary to readjust the quadrupole currents for each run, and the adjustment, which is done manually, takes several hours each time. As mentioned previously, a large initial beam coming into the quadrupolet, possibly resulting from the H_2^+ contamination of the beam by the process of gas charging, has led to poor transmission in the LEBT. In fact, this current is greatly influenced by gas pressure of the column, that matching condition at the entrance to the LEBT is subject to change from run to run, resulting in poor reproducibility.

The LEBT incorporates a double drift harmonic buncher (DDHB) which is patterned after the CERN design with minor modification. As the 402.5 MHz rf power source has not been available, only the 201.25 MHz buncher is being used.

Operation of the buncher has been severely troubled by the multipactor problem which causes the loss of field pulses. Experimental evidence has shown that the loss of pulses occurs while the radiation from the column varies drastically. Such a phenomenon is not yet completely understood, and thought to be originated from unexpected source of pollution in the line.

Considerable efforts have been put forth to cure this difficulty. So far, the maximum value of loss pulses in the buncher is about 10%, while it is running at 12.5 pps with pulse width of 150 μs. Work will continue in this aspect.

Linac

Linac tuning has proved straightforward. It is performed by trimming the currents of the quadrupoles about the computed values for transverse matching, by adjusting the phase and voltage of the buncher for longitudinal matching, and by setting the correct rf level for the tank field.

Tuning of the linac quadrupoles has proved to be much less critical than that of the quadrupolets in LEBT.

During a testing run, an open-circuit has happened to a quadrupole inside the drift tube number 32. However, proton beam is being accelerated by readjusting the currents of the quadrupoles adjacent to the absent one, with a loss of transmission about 10%.

Beam properties of the 10MeV linac during a typical run are: 200 mA from the injector, 120 mA at the input, 70 mA at the output. The transmission of LEBT is about 60%, and that of the tank is about 58%.

During operation, there were frequent malfunctions of the emittance measuring devices. In addition, the work on 10MeV linac has to be discontinued in order to clear the way for installation of the 35MeV linac. Systematic study of the beam properties was impossible at that time, and will be considered in the second phase of the project.

Design Features of the 35 MeV Linac

There are two options for the energy increase, namely, a separate second tank, a prolonged single tank. The former scheme can use the existing design to obtain an output energy of 37MeV.[1,2] However, it requires another rf power source which is among the most expensive equipment in the linac complex. In order to make the best use of the existing 5MW rf system, the single tank scheme is being adopted.

After evaluating several different geometries of the cavity and drift tubes by our computer program LAC and LAD, it finally ended up with a set of design specifications for a 35.5MeV linac (Table II).

The design features of the linac are summarized as follows.

1. Cavity length is extended from 7.27 m to 21.8 m without altering the structure of the 10MeV cavity. The cavity and drift tube diameters of the 0.75 to 10MeV section are 949mm and 180mm, while those of the 10 to 35.5MeV section are chosen to be 909mm and 160mm respectively. Thus high shunt impedance and reasonably high values of the transit time factor are maintained along the prolonged tank.[8]

2. A variational synchronous phase law is adopted. The phase varies gradually from -40° to -25° in the 0.75 to 10MeV section and keeps -25° along the remaining portion of the tank. By this approach, a wider longitudinal stable region for beam capturing and a saving on rf power are achieved.

3. A linear increase of the average axial field is designed. At tank entrance the field is 1.65MV/m, and tilted to 2.6MV/m at its exit. The rate of field tilting is about 0.044MV/m^2 which is much smaller than 0.075MV/m^2 that of the 10MeV tank. This choice of field law ensures higher accelerating rate, yet allowable peak surface field.

4. The LASL post couplers are used with periodicity 1 per two drift tubes. The desired field is thus stabilized against beam loading and tank detuning effects.

5. Twoport cavity excitation is uniquely arranged. The length of 35MeV tank is so chosen that the downstream port of the existing 10MeV tank happens to be at its 1/4 length point. Thus the rf branch for this port can be adopted as an upstream rf branch without any modification.

It is realized that to build a single tank linac of 14.6 λ long will be a difficult task. In order to reduce costs and speed installation, this approach seems to be a reasonable choice in our case of energy increasing.

Conclusion

In general, the 10MeV linac has been gratifying in performance and has met most of the design goals. Efforts will be made to improve reproducibility and reliability of the system in future.

Work on 35MeV linac is now in progress. It is planned to produce a 35 MeV beam in 1985, and to guide it along a 69m transport line to the application-laboratory for research in fast neutron therapy and medical isotope production.

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