DESIGN STUDY OF THE BEIJING 200 MeV PROTON LINAC

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Summary

In this paper a brief description of the design parameters of the Beijing 200 MeV Proton Linear Accelerator (BPL), some essential principles considered in the design and the three computer programs used are given.

Introduction

The BPL will serve as the injector of the 50 GeV Beijing Proton Synchrotron (BPS). It will be used to accelerate H^- beams mainly, and if the circumstance should arise, it could also be used to accelerate high intensity proton beams for other applications. We have designed this new machine with reference to the fundamental structure and the operating experience of the 200 MeV linacs at BNL[1] and Fermilab[2] and the new 50 MeV linac at CERN.[3] In certain aspects we have made some necessary changes, so that it may better suit our actual conditions and needs. Fundamental parameters of this machine were computed by means of the three computer programs prepared in our institute.

In order to adopt some existing rf structures and devices whose dimensions are determined by experiments, the resonant frequency of the BPL was chosen to be 201.25 MHz. All the transverse dimensions of the cavities are the same as those of BNL and Fermilab.

This machine is composed of 9 tanks with a total of 288 cells in them. Each tank contains an even number of cells. For the sake of stabilizing the accelerated fields in the tanks, we have decided to use post couplers from tank 2 to tank 9. The detailed geometry of each tank is shown in Table 1.

If a booster were to be added to the BPS, perhaps only the first four tanks would be needed in BPL.

Design Beam Performance Parameters

Type of accelerated particles	H^-, H^+
Input energy	750 KeV
Output energy	200.04 MeV
Beam intensity	30-50mA for H^- 100mA for H^+
Normalized emittance	(6-8) πmm-mrad
Output momentum spread	0.15-0.30%
Cavity resonant frequency	201.25 MHz
Beam pulse width	230μs (H^-)
Pulse repetition rate (Max.)	10 PPS

Choice of the Phase Law and the Field Law

In order to save rf power, increase the reliability of the rf system during operation and improve the characteristics of the beam, we have adopted a variational synchronous phase law, i.e., varying linearly with the number of the cells from $-35°$ at the input of the tank 1 to $-25°$ at the end of the tank 2 and then keeping a constant value of $-25°$ through the remaining tanks. We think that ϕ_s of $-35°$ at the input of the linac is necessary to provide a wider longitudinal stable region for capturing a high intensity beam with current possibly more than 100mA.

On the other hand, in order to reduce beam losses as much as possible, especially in the high energy region, the rate of decreasing $|\phi_s|$ should be slower than that of the phase damping. The value at $-25°$ is quite safe at the end of the tank 2 and in the remaining tanks.

Emphasizing the operational reliability of our machine, we have chosen to use a comparatively low average electrical field E (see Table 1). At the entrance of tank 1, E = 1.55 MV/m was taken. The rate of rise of E with length in tank 1 was chosen to be 0.075 MV/m^2.

As shown in the calculation of the linear particle dynamical program, if the effect of errors is neglected, a 100mA beam which is accelerated according to the phase law and the field law mentioned above will have a momentum spread of about 0.1%. The exciting rf power is then 18.89 MW, which is 14% less as compared with the constant phase ($-32°$) linac.

Calculation of the Field Configuration

In order to calculate the field configurations, stored energy, power dissipation, shunt impedance, transit time factors and resonant conditions, g/L etc., we referred to the method used at CERN[4] and have prepared the computer program LAC, which first calculates the potential function $U = H_\phi \cdot r$ in a cell using an analytical-numerical complex method. Then those electrical parameters mentioned above are derived. For some low energy cells, in the near axis region, where the variation of the field along the longitudinal axis is relatively large, we have tried to improve the accuracy of calculation by using a more dense mesh locally.

In our design, we have computed altogether 85 cells with given dimensions and obtained the factors F = E/E' in the following, which indicate the self-consistency of the program used:

$0.9903 \le F \le 1.0051$	for 25 cells in tank 1
$0.9850 \le F \le 0.9991$	for 16 cells in tank 2
$0.9921 \le F \le 1.0034$	for 18 cells in tank 3-4
$0.9912 \le F \le 1.0037$	for 26 cells in tank 5-9

It can be seen that these factors are very close to unity. At the same time, the resonant frequencies calculated with program LAC for several model cells agree very well with measured values. The comparisons between computations and measurements[5] are given in Table 2.

Generation of the Drift Tube Table

The length of each accelerator tank can be roughly estimated by the amount of rf power available from the source, which did not exceed 5MW for for 100mA beam current in our case. The length of the drift tubes, their positions along the tank and the exact length of each tank are worked out with program LAD, which is similar to the GENLIN program.[6] Program LAD can be used for situations in which the transit time factors T are either modified or not. Furthermore, program LAD can be used to calculate both the longitudinal dimensions for any given E and for that E which is chosen automatically so that the rate of acceleration ($dw/dz = eE \cdot T\cos\phi_s$) at the input of the downstream tank is equal to that at the output of the upstream tank, in order to reduce the discontinuity in longitudinal motion.

Choice of the Quadrupole Field Law and the Beam Matching Calculations in Transverse Motion

In the last few years, it has been found that the transverse normalized emittance blows up by a factor of 2-3 in tank 1 of most proton linacs. The main reason seems to be coupling between longitudinal and transverse motions by nonlinear space charge forces. The other reasons are the difficulty in obtaining perfect beam matching and the effect of the nonlinear external field forces. Therefore, the selection of the quadrupole field law should be a compromising consideration. That is to say, the maximum amplitude function of focusing system, β_{max}, should have a bit larger value in tank 1 so as not to make space charge effects too strong and remain almost constant along this tank to facilitate the matching adjustments). For instance, take $\beta_{max} = 4.7$. From tank 2 to tank 9, the β_{max} should be made to change continuously with acceleration so that the matching parameters between tanks can be adjusted easily. In this way, it is expected to minimize the growth in transverse emittance as much as possible. The quadrupole field law which we have chosen preliminarily is shown in Fig. 1.

The magnetic gradients and matching parameters are computed with program LAM, which includes linear space charge forces. The transverse and longitudinal dimensions of the beam are variable during the process of acceleration.

Parameters such as the transverse envelope (shown in Fig. 2) and the energy spread of the beam were also given by the program LAM.

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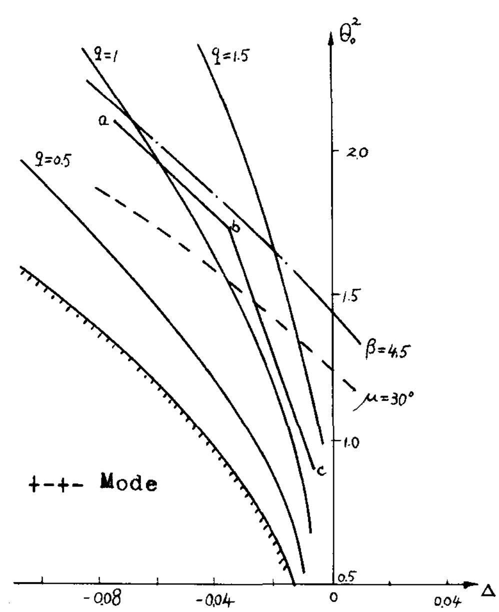

Fig. 1 - The quadrupole field law (abc) intended to be used in BPL.

Table 1: BPL 200-MeV Linac Drift Tube Table

Cavity Number	1	2	3	4	5	6	7	8	9	Total , Final
Output En.(MeV)	9.68	37.05	67.02	93.02	116.39	138.25	160.24	180.20	200.04	
Cavity Length (m)	7.272	18.675	17.016	16.170	15.595	15.524	16.561	15.858	16.545	139.220
Cavity Dia. (mm)	940	900	880	880	840	840	840	840	840	
D.T. Dia. (mm)	180	160	160	160	160	160	160	160	160	
B. H. Dia. (mm)	20—25	30	30	30	40	40	40	40	40	
B.H. Cor.Rad. (mm)	5	10	10	10	10	10	10	10	10	
D.T. Cor.Rad. (mm)	20	40	40	40	50	50	50	50	50	
Num.of Unit cells	56	60	36	28	24	22	22	20	20	288
Cell Length (mm)	60- 210	213-405	408-533	536-616	619-678	681-729	731-773	775-809	811-842	
G/L	.21-.30	.19-.31	.29-.36	.37-.41	.36-.39	.39-.42	.42-.44	.44-.45	.45-.47	
D.T. Length (mm)	47-145	173-278	288-337	339-364	392-409	410-421	422-431	432-438	439-445	
T	.67-.81	.87-.82	.83-.75	.75-.69	.73-.69	.69-.65	.65-.61	.61-.58	.58-.56	
Z (MΩ/m)	65.7- 72.9	71.5- 67.3	65.1- 62.3	62.3- 59.6	54.8- 52.8	52.8- 51.6	51.6- 50.6	50.6- 49.6	49.6- 48.5	
E (MV/m)	1.55- 2.08	1.93	2.45	2.46	2.31	2.31	2.31	2.31	2.31	
E_{smax} (MV/m)	8.3- 9.5	11.7- 9.5	12.5- 12.7	12.7- 13.0	12.4- 12.6	12.6- 12.8	12.9- 13.1	13.1- 13.3	13.4- 13.5	
Syn. Phase	-35°- -30.3°	-30.2°- -25°	-25°	-25°	-25°	-25°	-25°	-25°	-25°	
C.exi.power (MW)	0.44	1.30	2.17	2.24	2.25	2.39	2.69	2.62	2.79	18.89
Space of Cav. (mm)	210	600	1200	1000	1000	1000	1000	1000		

Table 2: Comparison Between Computation and Measurement *

Cavity Number	1	2	3	4	5	6	7	8
Half Length of Cav. (cm)	3.35	4.039	4.717	5.565	6.304	3.5	11.25	26.0
f (Measurement)(MHz)	202.47	200.70	198.81	200.57	198.94	198.58	200.61	201.32
f (JESSY) (MHz)	203.07	201.64	199.59	200.24	199.23	200.48	201.36	202.56
f (MESSYMESH) (MHz)	203.06	201.16	199.24	200.19	199.20	200.38	201.09	202.40
f (LAC) (MHz)	202.47	200.79	198.89	199.90	198.96	199.70	200.96	185.91**

* Cavities 1-5 Made by MURA, Cavities 6-8 Made by BNL

** Maybe the dimensions of this cavity used in computation with LAC program are not actual ones used in measurement at BNL.

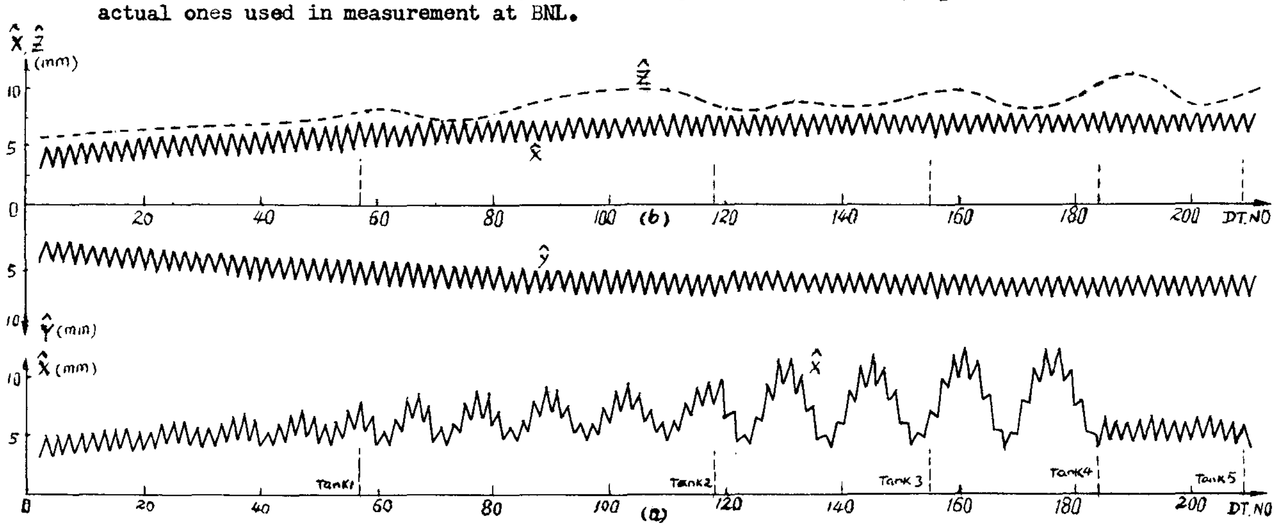

Fig.2 Linearized beam dynamics in the Linac tank 1-5, (a) unmatched beam envelopes, (b) matched beam envelopes.