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DESIGN OF THE 200-MEV PROTON LINAC FOR THE JAPAN HADRON FACILITY

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Abstract

A 200-MeV proton linear accelerator for the JHF has been designed [1][2]. A peak current of 30 mA with a 500 µsec pulse duration will be accelerated at a repetition rate of 25 Hz. The designed average current will be 200 µA at the beginning, and nearly 1 mA in the future. The linac consists of a 3-MeV radio-frequency quadrupole linac (RFQ), a 50-MeV drift tube linac (DTL) and a 200-MeV separated-type drift tube linac (SDTL) [3]. A frequency of 324 MHz has been chosen for all of the rf structures. A future upgrade plan of up to 400 MeV is also being considered, in which annular-coupled structures (ACS) of 972 MHz are to be used over an energy range of above 150 or 200 MeV. The balanced beam quality in both the transverse and longitudinal motions is one of the main features of the design. It can be achieved both by using an equipartitioning focusing scheme and by adopting an SDTL structure for the medium-energy range.

1 REQUIREMENTS

The required main parameters for the JHF proton linac are listed in Table 1. The construction plan of the linac consists of two stages. An output energy of 200 MeV and a peak current of 30 mA with a pulse length of 500 µsec at a repetition rate of 25 Hz are required in the first stage of construction. The required momentum spread of the output beam is ±0.1%. In order to reduce any beam losses after injection into the ring and to achieve high-intensity operation in the ring, a fast beam chopper in the low-energy region is required. It is crucial for the fast chopping system that the fraction of particles during the rising and falling times of the chopping pulse is very small.

2 DESIGN OF THE LINAC

2.1 Design features

The design is summarized in Table 2. The features of the design are as follows: (1) a frequency of 324 MHz has been chosen for all of the rf structures up to 200 MeV, resulting in no longitudinal transition; (2) an SDTL has been chosen in the energy range from 50 to 200 MeV, resulting in a higher effective shunt impedance and a separation of the transverse transition at 50 MeV from the longitudinal one at 200 MeV; (3) a 3-MeV RFQ has been chosen, resulting in the adoption of quadrupole magnets for the following DTL with sufficient focusing forces; (4) a transition energy of 150 or 200 MeV from the SDTL to the ACS has been selected in the upgrade plan; (5) the equipartitioning focusing method is applied; and (6) klystrons are used for all of the accelerating structures.

Table 1: Required main parameters of the linac.

	Initial stage	Final stage	
Particles	H^-	H^-	
Output energy	200	400	MeV
Peak current	30	60	mA
Beam width	500	500	µsec
Repetition rate	25	50	Hz
Average current	200	800	µA
Length	< 150	~ 220	m
Momentum spread	±0.1	±0.1	%

2.2 Ion source and RFQ

A promising experimental result (a peak injection current of 13.2 mA with a 90% emittance of 0.55 πmm-mrad was accelerated in the RFQ with a transmission efficiency of 83%) was achieved in the preinjector system (a volume production negative-hydrogen ion source and a 432-MHz RFQ) at KEK [4]. Therefore, a peak current of more than 30 mA from the ion source will be realized if

Table 2: Parameters of the JHF 200-MeV proton linac (DTL and SDTL).

	DTL	SDTL	
Frequency	324	324	MHz
Injection energy	3.0	50.3	MeV
Output energy	50.3	200.2	MeV
Length (structure only)	26.7	65.6	m
Length (including drift space)	27.1	91.1	m
Number of tank	3	31	
Number of klystron	3	14	
Rf driving power	3.3	16.6	MW
Total rf power (30 mA)	4.7	21.1	MW
Total length		119.1	m
Total power (30 mA)		25.8	MW
Peak current		30	mA
Beam width		500	µsec
Repetition rate		25	Hz
Average current		200	µA
chopping ratio		~0.56	

Table 3: Parameters of the DTL.

Tank number	1	2	3	
Output energy	19.7	36.7	50.3	MeV
Length	9.9	9.4	7.3	m
Number of cell	76	43	27	
Rf driving power	1.06	1.17	1.06	MW
Total rf power (30 mA)	1.56	1.68	1.47	MW
Accelerating field	2.5	2.7	2.9	MV/m
Stable phase	-30	-26	-26	degree
Bore diameter	13	22	26	mm

some increases in the transverse emittance are allowed. A four-vane type 324-MHz RFQ has been designed [5]. It accelerates ions from 50 keV to 3 MeV. The detailed design is under development.

2.3 DTL

A 324-MHz DTL accelerates beams from 3 to 50 MeV. It consists of three post-stabilized tanks [6]. An accelerating field of 2.5 MV/m is determined from the viewpoints of satisfying the equipartitioning condition and being sufficiently low for avoiding any discharge problem. All drift tubes contain quadrupole magnets. Model magnets of the hollow-conductor type with a magnetic-field gradient of 117 T/m were designed and successfully fabricated [7]. The parameters of the DTL are listed in Table 3.

2.4 SDTL

A 324-MHz SDTL is adopted for medium-energy acceleration from 50 to 200 MeV. Each tank consists of five unit cells. Since the focusing magnets (doublet) are placed between two adjacent SDTL tanks, the shunt impedance can be freely optimized without any geometrical restriction from the quadrupole magnets, which are placed in the drift tubes in the conventional DTL system. There are many other advantages in the SDTL system: the number of required focusing magnets has been reduced, fabrication of drift tubes has become easier, stabilizing devices are not necessary, and the required alignment accuracy of the drift tubes and each tank has been reduced. The parameters of the SDTL are listed in Table 4.

2.5 ACS

An extensive beam-dynamics calculation regarding an upgrade of the output energy up to 400 MeV by using the CCL-type structure was performed [1]. It was concluded that an accelerator complex of DTL, SDTL and the ACS is a good choice from the viewpoints of both the output beam quality and the accelerating efficiency. Also, it was pointed out that the ACS has more balanced characteristics concerning both the shunt impedance and the field symmetry [8]. A frequency of 972 MHz, three-times as high as the fundamental frequency, and a transition energy of above 150 or 200 MeV were selected. The fundamental RF issues concerning the ACS have already been solved, and a number of high-power RF tests using the 1296-MHz prototype cavities were successfully performed [9]. Therefore, a future extension using a 972-MHz ACS will be possible with some modification efforts.

Table 4: Parameters of the SDTL.

Length of unit tank	1.48 - 2.61	m
Number of tank	31	
Number of cell	155	
Rf driving power	0.34 - 0.71	MW
Total rf power (30 mA)	0.46 - 0.86	MW
Accelerating field	3.75	MV/m
Stable phase	-26	degree
Bore diameter	30	mm

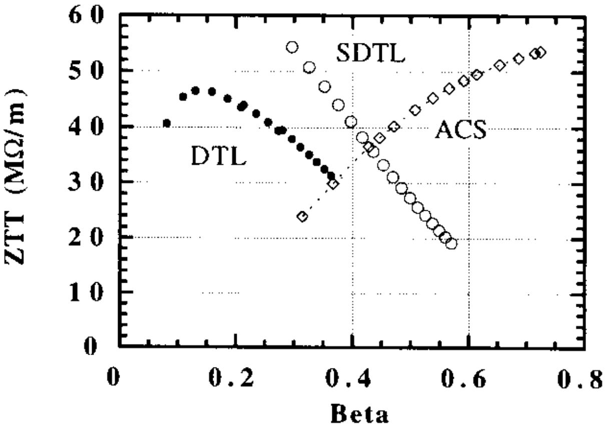

Figure 1: Effective shunt impedance used for the JHF proton linac.

The effective shunt impedance for the three kinds of rf structures mentioned above is plotted in Fig. 1.

3 BEAM DYNAMICS

A beam simulation was performed using the code LINSAC [10]: the code includes an accurate field distribution in an accelerating gap, and takes into account any space-charge effects by the particle-particle method. It includes all space harmonics into the calculation. Both the emittance growth and halo formation during acceleration were carefully studied, since they are one of the main issues in designing the high-intensity JHF proton linac.

3.1 DTL and SDTL

Both the transverse and longitudinal focusing parameters were determined based on equipartitioning theory combined with coupled envelope equations for the bunched beam [11][12][13]. The equipartitioning condition is approximately satisfied during acceleration in the design. Figure 2 shows both the transverse and longitudinal phase advances in the DTL. Two sets of normalized rms emittances at the entrance of the DTL were used in the simulation through the DTL and the SDTL (Type A:

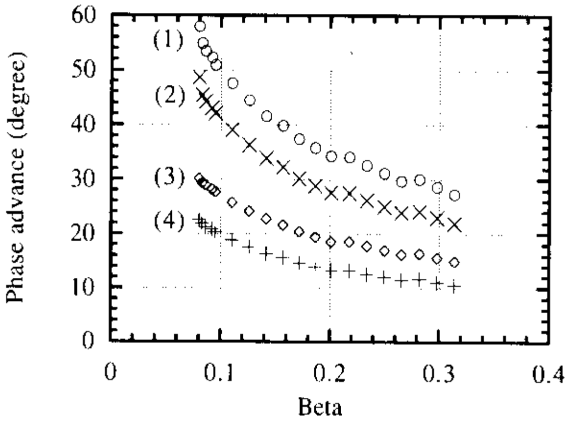

Figure 2: Phase advance in both the transverse ((1) 0 mA and (2) 30 mA) and longitudinal ((3) 0 mA and (4) 30 mA) phase spaces along the DTL vs. beta (v/c).

0.187 πmm-mrad and 0.133 πMeV-deg and Type B: 0.375 πmm-mrad and 0.266 πMeV-deg). Compared with the transverse-focusing design with a constant phase advance of 60 degrees, the calculated results with the equipartitioning focusing design show better beam qualities totally, especially in both the emittance growth and halo formation in longitudinal phase space [2]. For the type-A beam, the ratios of the emittance growth between two focusing methods (the equipartitioning focusing and the constant phase advance one) are 1.22 and 0.62 in the transverse and longitudinal rms emittances, respectively. It has been found that the ratio of halo-like particles is about on the order of 10^{-3} ~10^{-4} in a simulation with 48000 particles. The ratios of halo formation between these two focusing methods are nearly equal in the transverse motion and 0.52 in the longitudinal motion. Here, halo-like particles in the transverse motion are defined by those outside 6.5 times as far as the standard deviation of the radial distribution of the output beam, while halo-like particles in the longitudinal motion are defined by those outside 12.5 times as far as the longitudinal output rms emittance.

3.2 MEBT

A beam-transport line, 2.7 m long between the RFQ and the DTL (MEBT), has three purposes: achieving both transverse and longitudinal beam-matching, chopping the beam for reducing beam losses after injection into the ring and measuring the beam properties before injection into the DTL [14][15]. It consists of eight quadrupole magnets, two bunchers and two rf-chopping cavities (referred to as RFD) [16]. Detailed simulation results show that high performance in the chopping operation can be achieved by using the RFD: the number of unstable particles at the DTL exit (50 MeV) during the transient times is less than 0.08% of the total injection particles [14][15].

Table 5: Parameters of the RF power source.

Repetition rate	50	Hz
Pulse width	620	μsec
Number of klystrons	19	
Peak output power	2.0	MW

4 RF POWER SOURCE

A high-power rf system has been designed on the basis of accumulated knowledge and experience during the construction and operation of the JHP test stand [17]. The main parameters are listed in Table 5.

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