# DESIGN OF THE JHF 200-MEV PROTON LINEAR ACCELERATOR

T. Kato and Y. Yamazaki, KEK, 1-1 Oho, Tsukuba-shi, Ibaraki-ken, 305, Japan

*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 considered, in which annular-coupled structures (ACS) of 972 MHz are used in an energy range of above 150 or 200 MeV. There are three distinct features in the design. The first is stable operation with high performance for a beam-loss problem. The second is a total high shunt impedance, achieved by adopting the SDTL structure. The third is the adoption of klystrons for all of the accelerating structures.

## 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 a low-energy region is required. It is crucial for the fast chopping system that the fraction of the particles during 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 and suppression of the space-charge effects, (2) an SDTL has been chosen in the energy range from 50 to 200 MeV, resulting in a higher effective shunt impedance, (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) the 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 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.

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

| | DTL | SDTL | |
|---|---|---|---|
| Frequency | 324 | 324 | MHz |
| Injection energy | 3.0 | 50.1 | MeV |
| Output energy | 50.1 | 200.0 | MeV |
| Length (structure only) | 27.0 | 65.8 | m |
| Length (including drift space) | 28.5 | 92.3 | m |
| Number of tank | 3 | 31 | |
| Number of klystron | 3 | 14 | |
| Rf driving power | 3.9 | 16.7 | MW |
| Total rf power (30 mA) | 5.3 | 21.2 | MW |
| Total length | | 122.2 | m |
| Total power (30 mA) | | 26.6 | 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 | 19.2 | 35.4 | 50.1 | MeV |
| Length | 10.4 | 8.9 | 7.8 | m |
| Number of cell | 80 | 41 | 29 | |
| Rf driving power | 1.16 | 1.36 | 1.40 | MW |
| Total rf power (30 mA) | 1.64 | 1.84 | 1.84 | MW |
| Accelerating field | 2.5 | 2.7 | 2.9 | MV/m |
| Stable phase | -30 | -26 | -26 | degree |
| Bore diameter | 13 | 22 | 26 | mm |

### *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 holo-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 in 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, optimization of the shunt impedance can be easily performed without any geometrical restriction from the quadrupole magnets, which are usually placed in the drift tubes for DTL system. It is also an advantage from the viewpoint of mechanical engineering that no stabilizing devices are required in the SDTL system. The parameters of the SDTL are listed in Table 4.

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 | 0.35 - 0.64 | MW |
| Total rf power (30 mA) | 0.48 - 0.78 | MW |
| Accelerating field | 3.86 - 3.6 | MV/m |
| Stable phase | -26 | degree |
| Bore diameter | 30 | mm |

### *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, SDL and the annular coupled structure (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 is the one which has balanced characteristics of both the shunt impedance and the field symmetry [8]. A frequency of 972 MHz, three-times the fundamental frequency, and a transition energy of above 150 or 200 MeV were selected. The fundamental RF issues concerning the ACS were already solved, and a number of high-power RF tests using the 1296-MHz model cavities were successfully performed [9]. Therefore, a future extension using a 972-MHz ACS will be possible with some efforts of modification.

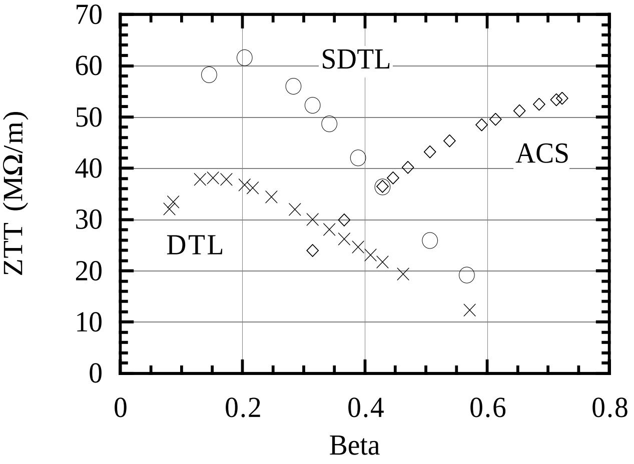

Figure 1: Effective shunt impedance used for the JHF proton linac.

The effective shunt impedance for 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 account of any space-charge effects by the particle-particle method. It includes all space harmonics into the calculation. Both 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 on the basis of 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:

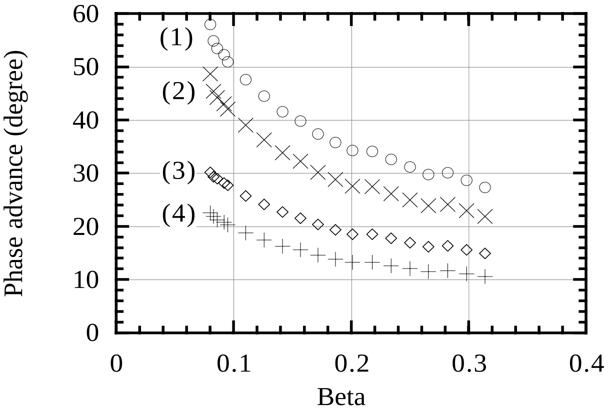

Figure 2: Phase advance in both the transverse ((1) 0 mA and (2) 30 mA) and longitudinal ((3) 0 mA and (4) 30 mA) phase spaces along the DTL vs. beta (v/c).

0.187 πmm-mrad and 0.133 πMeV-deg and Type B: 0.375 πmm-mrad and 0.266 πMeV-deg). Comparing 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 is found that the ratio of halo-like particles is about an 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 at the outside of 6.5 times the standard deviation of the radial distribution of the output beam, while halo-like particles in the longitudinal motion are defined by those at the outside of 12.5 times the longitudinal output rms emittance.

### *3.2 MEBT*

A beam-transport line, 2.3 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]. It consists of eight quadrupole magnets, two bunchers and two rf-chopping cavities (named RFD) [15]. Detailed simulation results show that high performance in the chopping operation can be achieved by using the RFD: the number of unstable particles during transient times is less than 0.08% of the total injection particles [16] even in a chopping operation with a rather large loaded Q-value of about twenty.

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

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

## 5 ACKNOWLEDGMENTS

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## 6 REFERENCES

[1] T. Kato, ‘Design of the JHP 200-MeV Proton Linear Accelerator,’ KEK report 96-17 (1997).
[2] T. Kato et al., ‘JHF Accelerator Design Study Report, Section 4, 200-MeV Linac,’ KEK report 97-16 (1998).
[3] T. Kato, ‘Proposal of a Separated-type Proton Drift Tube Linac for a Medium-Energy Structure,’ KEK Report 92-10 (1992).
[4] A. Ueno et al., ‘Beam Test of the Pre-Injector and the 3-MeV H RFQ with a New Field Stabilization PISL,’ Proc. 1996 International Linac Conf., p.293 (1996).
[5] A. Ueno, ‘JHF Accelerator Design Study Report, Section 4.4, Preinjector,’ KEK report 97-16 (1998).
[6] F. Naito et al., ‘Rf Characteristics of a High-Power Model of the 432 MHz DTL,’ Proc. 1994 International Linac Conf., p.137 (1992).
[7] K. Yoshino et al., ‘JHF Accelerator Design Study Report, Section 4.5, Accelerating structure,’ KEK report 97-16 (1998).
[8] Y. Yamazaki, ‘Recent Technological Development of Accelerating Structures,’ Proc. 1992 Linear Accel. Conf., p.580 (1992).
[9] T. Kageyama et al., ‘Development of Annular Coupled Structure,’ Proc. 1994 International Linac Conf., p. 248 (1994).
[10] T. Kato, ‘Beam Simulation Code Using Accurate Gap Field Distributions in a Drift Tube Linac,’ Proc. 1994 International Linac Conf., p.523 (1994).
[11] R. A. Jameson, ‘Beam-Intensity Limitations in Linear Accelerators,’ IEEE Trans. Nucl. Sci. NS-28, 2408 (1981).
[12] R. A. Jameson, ‘On Scaling & Optimization of High-intensity Low-beam-loss RF Linacs for Neutron Source Drivers’, AIP Conference Proceedings 279 (1993) 969.
[13] M. Reiser, ‘Theory and Design of Charged Particle Beams,’ Section 5, John Willy & Sons, 1994.
[14] S. Fu and T. Kato, ‘JHF Accelerator Design Study Report, Section 4.3.4, The medium energy beam-transport line,’ KEK report 97-16 (1998).
[15] T. Kato, ‘New Design of an RF Beam Chopper,’ Proc. 7th Symposium on Accelerator Science and Technology, p.288 (1989).
[16] S. Fu and T. Kato, ‘Design of Beam-transport Line between the RFQ and the DTL for the JHF 200-MeV Proton Linac,’ submitted to this conference.
[17] S. Anami et al., ‘JHF Accelerator Design Study Report, Section 4.6, RF source,’ KEK report 97-16 (1998).