THE 1 GeV PROTON LINAC FOR THE JAPANESE HADRON FACILITY

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Abstract

The 1 GeV proton linac is designed for the Japanese Hadron Facility. Our program includes developments of a high peak current and low emittance Cs free H⁻ ion source, a long RFQ linac, a drift-tube linac with high gradient SmCo permanent quadrupole magnets, and a high-ß linac that can accelerate the high beam current stably and efficiently. Development of reliable high power RF sources is crucial for stable operation of the linac. Present status of these developments is reported together with parameters of the linac.

Introduction

The Japanese Hadron Facility[1] includes construction of the 1 GeV proton linac to inject proton beams efficiently into the ring accelerator. Negative hydrogen beams will be accelerated for their high injection efficiency. Design parameters are listed in Table I. The linac is composed of a volume production type H⁻ ion source, a 432 MHz RFQ linac (3 MeV), a 432 MHz drift-tube linac (150 MeV) and a 1296 MHz high-ß linac (1 GeV). Detailed parameters of each component are presented in Ref. 2 and 3. Thus, only basic parameters are listed in Table II.

Accelerating Frequencies and RF Power Sources

A high energy and high intensity proton linac with a limited length requires very high rf power. One of economical ways to obtain very high rf power is to reduce a number of rf sources by increasing an rf power of each rf source as far as possible. This is also advantageous for purposes of stable operation and easy maintenance. Another way is to increase an accelerating frequency, since a shunt impedance of an accelerating cavity with the same figure is proportional to a square root of its accelerating frequency. This is also advantageous for stable operation, since a discharging limit is proportional to a square root of the frequency. Actually both of the ways have been chosen in a recent trend of the proposed design parameters for e^+e^- linear colliders.

Difficulty arises from the long pulse length (600 µs) and high duty factor (3 %). The long pulse length seriously limits the maximum rf power of a single rf source that is stably usable, since the discharging or sparking limit rapidly decreases as the rf pulse length increases. The high duty factor limits the highest possible accelerating frequency. As the frequency increases, sizes of accelerating cavities and klystrons decrease, so that cooling of these RF components becomes difficult.

Taking these factors into account, we have chosen 1296 MHz (L band) for the frequency of the high-ß linac and 432 MHz (UHF band) for those of the RFQ and DTL. Also, we estimate that the maximum rf power of a single rf source (klystron) is 5 to 6 MW[4] for the 600 µs pulse length and that the power stably provided without failure is 3 to 4 MW. The design parameters shown in Table II are based upon this estimation. Therefore, it is crucial to test possibility and performance of the 6 MW rf source for success of the project. Also, for extremely stable operation of the linac, accelerating cavities and other RF components such as RF windows and circulators should be fully tested up to the 6 MW power level.

For these purposes a high power test station is being prepared. A line-type modulator with an output power of 15 MW has been constructed as shown in Fig. 1 and is being tested. At present a pulse length of its pulse-forming network (PFN) is 200 µs, but will be soon lengthened to 600 µs. The line type was chosen for its excellent stability with a de-Qing circuit and its high efficiency. Design of the modulator is detailed in Ref. 2 and 5. After the isolated test of the modulator is finished with a dummy load, a 5 MW klystron (THOMSON TH2104A) and a pulse transformer (step-up ratio of seven) will be installed.

Table I Design parameters of the H⁻ linac

Energy	1 GeV
Total length	~ 500 m
Average current	> 200 µA
Repetition rate	50 Hz
Peak current	20 mA
Beam pulse length	400 µs
RF pulse length	600 µs

Table II Parameters of components

H⁻ ion source		
Type	Volume production type	
Peak beam current	20	mA
Normalized emittance	1	πmm·mrad
RFQ		
Input energy	50	keV
Output energy	3	MeV
Frequency	432	MHz
Vane length	2.7	m
Minimum bore radius	0.236	cm
RF power	0.8	MW
Transmission (20 mA)	94	%
Normalized emittance (90 %)	1.3	πmm·mrad
DTL		
Output energy	148	MeV
Frequency	432	MHz
Total length	83	m
Bore radius	0.5	cm
Number of cells	342	
Number of tanks	13	
RF power	12	MW
Normalized acceptance (90 %)	8.9	πmm·mrad
High-ß linac		
Output energy	1	GeV
Frequency	1296	MHz
Total length	411	m
Tank length	303	m
Bore radius	1.5	cm
Number of cells	3568	
Number of tanks	152	
RF power	99	MW
Klystron output power	3	MW
Number of klystrons	36	
Normalized acceptance (90 %)	29	πmm·mrad

Ion Source and RFQ Linac

A volume-production type H⁻ ion source is being developed, since it has potentiality to produce high intensity H⁻ beam with low emittance and it uses no cesium vapor that reduces the breakdown voltage of the following RFQ. A test H⁻ ion source is being used to optimize parameters of a magnetic filter, to solve the problem of heavy electron beam loading and to study dependence of the beam current density on the volume of the ion source.

A 432 MHz RFQ linac will accelerate the beam from 50 keV to 3 MeV. Design study described in Ref. 2 and 6 indicates that its vane length becomes 2.7 m long (about four times of the wave length) resulting in very severe specification for its structual dimension. Mechanical design of a cold model is in progress to meet the severe specification.

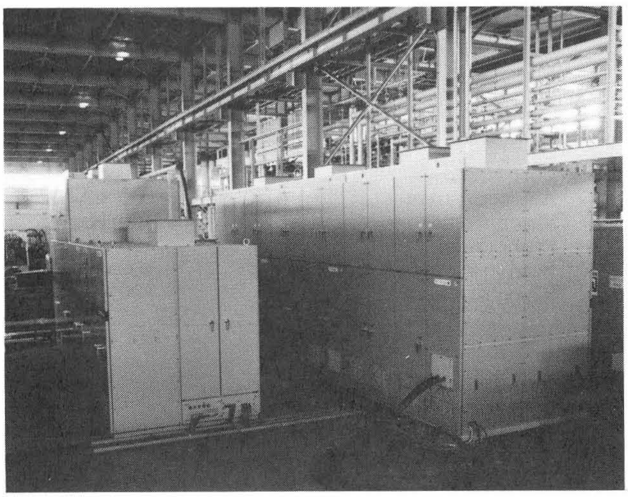

Fig. 1 A 15 MW line-type modulator.

Drift-tube Linac

A 432 MHz drift-tube linac (DTL) will accelerate the beam from 3 MeV to 148 MeV. Detailed design parameters of the DTL are described in Ref. 2 and 7. Rather high injection energy and high accelerating frequency make it possible to use permanent quadrupole magnets such as SmCo and Nd-Fe that require neither of wiring nor water-cooling and become maintenance-free. However, it is difficult to seal drift tubes containing these permanent magnets, since the magnets cannot stand the high temperature used for the silver brazing and the strong magnetic field produced by the magnets inhibits conventional use of the electron-beam welding (EBW).

Copper-electroplating method will be usuful to seal the drift tubes, since the electroplating is possible at room temperature. Also, it is expected that the magnetic field has little effect on quality of the electroplating. Thus, drift tubes made of stainless steel and oxygen-free copper with the permanent magnets were copper-plated at the positions shown in Fig. 2 to seal them from vacuum. The drift tube thus fabricated is shown in Fig. 3. Although further improvement is necessary for flow of the electroplating fluid, the electroplating method is promising.

It will be another method to expose the permanent magnets to vacuum. In order to test this possibility outgassing measurement of the SmCo was made in vacuum. A stainless-steel (SUS304) chamber with an inner surface of 175 cm^2 was propared and evacuated through an orifice with a conductance of 1 l/s. A SmCo specimen with a surface of 29.8 cm^2 (45 g) was situated in this chamber. Measured outgassing rate of the SmCo was 3.7×10^{-9} Torr l/s cm^2 after 50 hour evacuation and 1.2×10^{-9} Torr l/s cm^2 after 450 hour evacuation. If the SmCo is exposed to vacuum, the vacuum pressure of the 4.7 m-long first tank will become by about nine times worse, where the outgassing rate of copper is estimated to be 7×10^{-11} Torr l/s cm^2. Improvement of the outgassing rate is necessary, for example, by careful handling of the SmCo during fabrication process.

A cold model of the first DTL tank with post couplers is being fabricated to obtain necessary data for final detailed design. At this stage we had to choose either of gradient-field type or flat-field type for the first DTL tank. In order to study difference between these two types beam-tracking calculations throughout the DTL and high-ß linac were made for the 20 mA output beam from the designed RFQ linac. An accelerating field of 3 MV/m was used for the flat-field type, while it was varied from 1.9 to 2.9 MV/m as the beam was accelerated from 3 to 12 MeV for the gradient-field type. Capture efficiencies of the high-ß linac and energy spreads of the output beams of the high-ß linac were compared. No distinguished difference was recognized in the results of the calculations. On the other hand, the gradient-field type DTL becomes longer than the other, if the maximum field is limited, and will excite the unwished post mode because of the field difference. Thus, we chose the flat-field type for the first DTL.

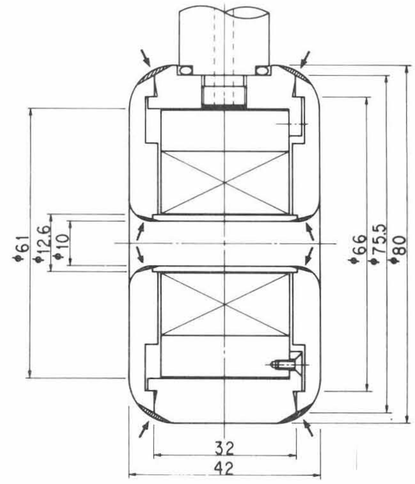

Fig. 2 Positions of the electroplating welding of the drift tube.

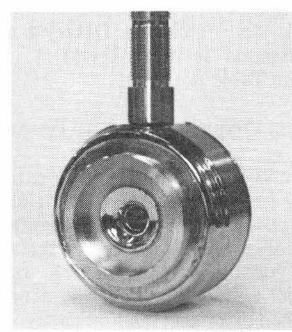

Fig. 3 A drift tube welded with an electroplating method.

High-ß Linac

Standing wave coupled-cell cavities operated at the $\pi/2$ mode will be used for the high-ß linac. Among various possible candidates a side-coupled structure (SCS)[8] and an alternating-periodic structure (APS)[9,10] are being developed. A computer program MAFIA[11] (a three dimensional numerical solution program for the Maxwell's equation) is being extensively used in our study of the structures[12]. Accuracy of the calculation was tested by comparing a result of the calculation with that of the measurement of a model cavity as shown in Table III with Fig. 4. Taking into account the accuracy thus obtained one can use results of calculations with the MAFIA in determining parameters of cavities. For example, coupling constants of the SCS are calculated as shown in Fig. 5, being dependent upon the distance between the coupling and accelerating cells.

So far, two fabrication methods have been used for the SCS; one for LAMPF[8] and the other for RTM[13]. The latter method is simpler and easier than the former, but seals water-cooling channels from vacuum by silver brazing. Although no problem has been reported for the latter method, more reliability is desirable for long term operation. On the other hand, the former conventional method has difficulty in brazing a curved surface of a side-coupling cell to that of an accelerating cell. However, recent development of numerically controlled (NC) cutting machines has improved accuracy of machining of the brazed surfaces, making the brazing of the coupling cell to the accelerating cell more reliable. An example of the cold models of the SCS thus fabricated is shown in Fig. 6.

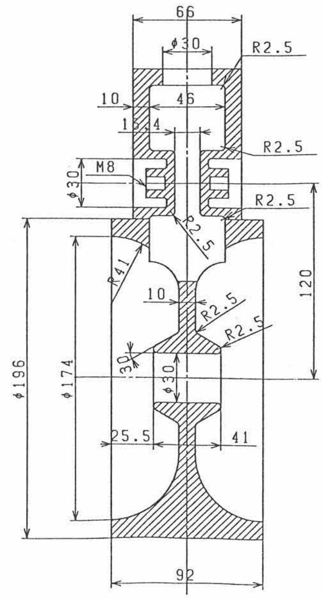

Fig. 4 Side-coupled structure used in the calculation and measurement for Table III and Fig. 5.

Table III Effects of a coupling slot on the side-coupled structure. The distance between the coupling and accelerating cells is 12.0 cm. The mesh size of 0.5 x 0.5 x 0.25 cm^3 is used in the calculation with MAFIA.

	Calculated	Measured
Coupling	3.2 %	4.4 %
Variation of the accelerating-mode frequency	-23.3 MHz	-24.0 MHz
Variation of the coupling-mode frequency	-48.5 MHz	-49.6 MHz
Decrease of the quality factor of the accelerating mode	5.1 %	

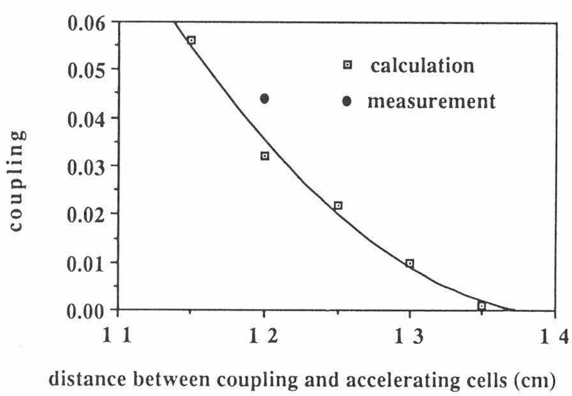

Fig. 5 Dependence of coupling constants on the distance between the side-coupling and accelerating cells.

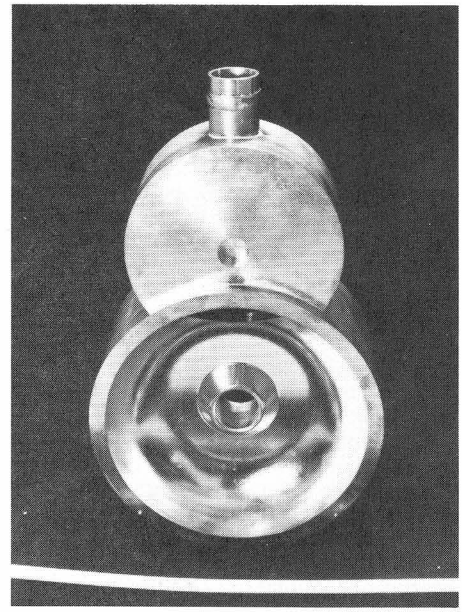

Fig. 6 A cold model of the side-coupled structure.

In fabricating either of the SCS and APS it will be a common process to weld or braze stacked cells to form an accelerating tank. Before this process tunings of cells are possible, for example, by machining their inner surfaces again, while the tunings are difficult after the process. Thus, for this process a method that leaves no deformation is desirable. Four methods of a silver-brazing, electron-beam welding, electroplating welding and diffusion welding were tested to fabricate APS cavities and the deformations were measured as shown in Table IV. Since both of the silver-brazing and electroplating welding yielded the excellent results, one of these two methods will be adopted.

Table IV Deformations of the APS cavity arising from weldings or brazings.

	deformation of diameter (μm)	deformation of cell length (μm)
Electroplating	8 ± 3*	-4 ± 1
Silver brazing	7 ± 4	-3 ± 1
EBW	9 ± 8	-240 ± 58
Diffusion welding	33 ± 12	-121 ± 42

* standard deviation of several samples

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