DEVELOPMENT OF A HIGH-POWER 432 MHz DTL

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Abstract

A high-power model of a 432 MHz Drift-Tube Linac is under construction. It will accelerate H^- ions from 3 to 5.4 MeV, and is a prototype of the DTL for the Japanese Hadron Project. Several new techniques have been developed for constructing the DTL: fabricating and assembling methods of permanent quadrupole magnet and a drift tube, an alignment of drift tube, and a method to connect the tanks.

Introduction

A 1-GeV high-intensity proton linac is being considered as an injector for a ring accelerator of the Japanese Hadron Project (JHP) [1]. The proton linac comprises a radio-frequency quadrupole (RFQ), a drift-tube linac (DTL) and a coupled-cell linac (CCL).

The DTL accelerates H^- ions from 3 to 148 MeV. The total length of the DTL, comprising 13 tanks, is about 80 m. The length of each tank is thus about 6 m. The resonant frequency (432 MHz) is about 2-times that of a conventional 200 MHz DTL. The increased frequency reduces the size of the DTL. The dimensions of 432 MHz DTL are so small to allow the use of precision machining tools. For high-duty DTL it is very important to take into account the cooling efficiency of the components. In this case copper is preferable; we thus decided to make the entire DTL of oxygen-free copper (OFC). Each tank comprises short unit tanks (about 0.6-m long) in order to mount drift tubes in the tank by hand. Moreover, it is relatively easy to fabricate a tank using high-precision instrument, since the unit tank is small enough to place on the instruments.

The fabrication techniques of the DTL have been carefully investigated because of a downsizing of the OFC cavity. Several new fabrication techniques and assembling tools have been developed on the basis of the new DTL specifications. A high-power model of the DTL is under construction in order to establish fabrication techniques and to carry out beam tests. The model is 1.2-m long and 0.44 m in inner diameter. It comprises two unit tanks and 17 drift tubes. The DTL accelerates H^- ions from 3 to 5.4 MeV. The post couplers, which were studied using the low-power model [2,3], are installed in every other cell of the DTL. Construction of the DTL is undergoing steady progress; its schematic view is shown in Fig. 1.

The fabrication methods developed for the DTL and described in the following sections are as follows:
(a) fabrication of permanent magnet piece,
(b) assembly of permanent quadrupole magnet (PQM),
(c) assembly of a drift tube with PQM,
(d) alignment of the drift tubes in the tank, and
(e) connection of two adjacent unit tanks.

Fabrication of the permanent magnet piece

The beam quality from a DTL strongly depends upon the quality of quadrupole magnets in drift tubes. The beam dynamics require the following specifications for a quadrupole magnet:
(a) An integrated field of 5.5 T for 3-MeV H^- injection. The magnetic field gradient is thus 184 T/m for a magnet length of 30 mm.

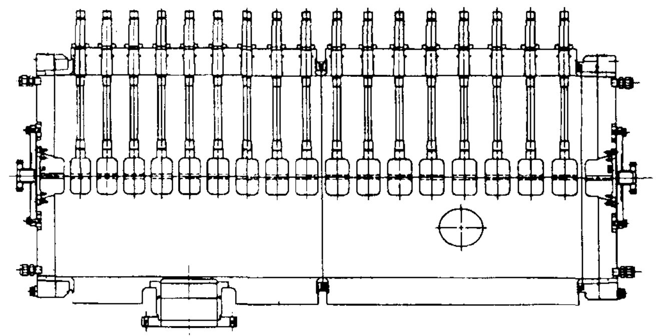


Fig. 1 Schematic view of the model DTL.

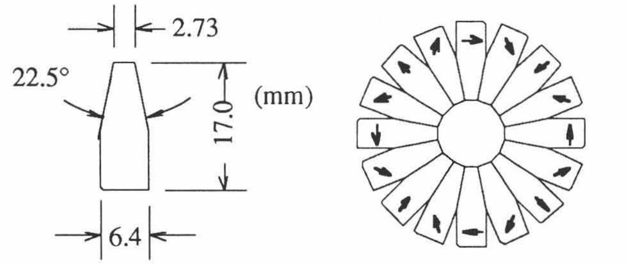
(b) The deviation of the field center of the quadrupole magnet from the beam axis must be less than 20 μm (r.m.s.).
(c) The standard deviation of the field gradient is within 4.4%.

A permanent quadrupole magnet (PQM) was chosen as the focusing magnet, since its field strength meets the requirements; it is also sufficiently small to be easily fixed in a 432-MHz drift tube. Moreover, it requires neither cooling nor maintenance. There are two candidates for the PQM material: Nd-Fe-B and Sm-Co. A Nd-Fe-B magnet is superior to a Sm-Co magnet due to the residual magnetization (Br) and hardness. However, the Curie point of the Nd-Fe-B magnet (about 300 ^{o}C) is less than that of the Sm-Co magnet (about 900 ^{o}C) . Since radiation damage is relatively small for a magnets with a high Curie point, the damage to the Sm-Co magnet is less than that of the Nd-Fe-B magnet.

A Nd-Fe-B permanent magnet which satisfies specification (a) was chosen for the PQM of the lowest-energy tank. For a higher-energy tank, PQMs are made of Sm-Co, since radiation damage increases with the energy of H^- ions. The PQM comprises 16 pieces in order to achieve a strong magnetic field [4].

The specifications for each magnet piece depends upon the assembling procedure of the quadrupole magnet. The following two types of procedures have been considered:
(1) Manufacture the magnet pieces with moderate accuracy, and repeat the assembling of a PQM by exchanging the magnet pieces until the quality of the PQM satisfies the specifications.
(2) Manufacture the magnet pieces with high accuracy, and assemble a PQM precisely only once.

We chose the latter procedure. In order to achieve the required accuracy regarding the magnetic properties and dimensions of the external form of each piece, we investigated and modified the entire fabrication process of the magnet from the pressing of magnetic powder in the magnetic field to the final polishing of the piece. The external form of each piece is precisely corrected in order to adjust the magnetization direction according to the measurement of the magnetization direction and the field strength. The magnet dimensions are shown in Fig. 2-a. Figure 2-b shows the arrangement of magnet pieces for the PQM. The measured magnetization directions of the pieces are summarized in Fig. 3, showing three types of the magnetization direc-



(a) Dimensions of a magnet piece.

(b) Schematic view of PQM. Arrows in the pieces indicate the magnetization directions.

Fig. 2 Permanent quadrupole magnet.

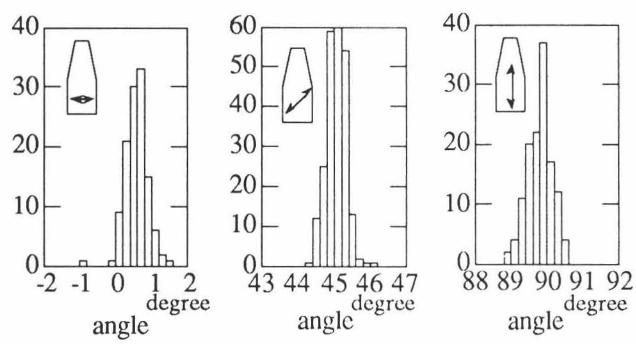


Fig. 3 Measured magnetization directions of magnet pieces. The ordinate shows the number of pieces. Average angles for three kinds of piece are 0.6 ,45.1 and 89.8, respectively. All standard deviations are 0.3.

tions (0, 45, 90 degree).

Assembling the quadrupole magnet

The PQM assembling method is closely related with that of a drift tube, since the PQM is fixed inside the drift tube. We attempted the following two PQM assembling methods:

(1) The magnet pieces are placed inside a cylindrical holder in order to form the magnetic quadrupole field. Since the holder fixes the magnet pieces in the desired position, the PQM is precisely arranged, if the magnet pieces have been fabricated accurately. After assembling the PQM, it is enclosed in a drift tube. A schematic view of this process is shown in Fig. 4-a. The drift tube has three seams which must be joined. One seam exists near the bore of the drift tube where the fringing field of the PQM is strong.

(2) The drift tube comprises two shells: the inner and outer shells. The permanent magnets are directly fixed around the central beam pipe of the inner shell by an assembling jig. The inner shell is then inserted into the outer shell. Although the assembling jig of the PQM's is not simple, there is no seam near the bore of the drift tube, where high magnetic fields are present. Figure 4-b shows the scheme of the second method.

The development of both methods mentioned above has been completed. For the model DTL, the method (2) was chosen in order to avoid a seam to be joined near to the bore. Details concerning jig assembling of the PQM were reported at the previous LINAC conference [5]. After assembling the PQM in the inner shell made of OFC, a band made of stainless steel fixes its form. The band comprises two half rings, both of which are connected together by tungsten inert gas (TIG) welding that exerts the binding force on the PQM. TIG welding increases the temperature of the PQM; heat absorbers are therefore placed on the band during the welding process in order to keep the temperature of the PQM to less than about 50 ^{o}C. No deterioration in the properties of magnetic field was observed after the welding.

The differences between the field centers of PQMs and the mechanical centers of inner shells were measured using a rotary coil for the four completed samples. The results are 2, 3, 16 and 8 μm, respectively. The measurement error was about $\pm$10 μm, mainly from uncertainties of the coil dimension and the PQM position on the movable stage of the coil. The measured field gradient agreed with the value calculated with the code PANDIRA [4].

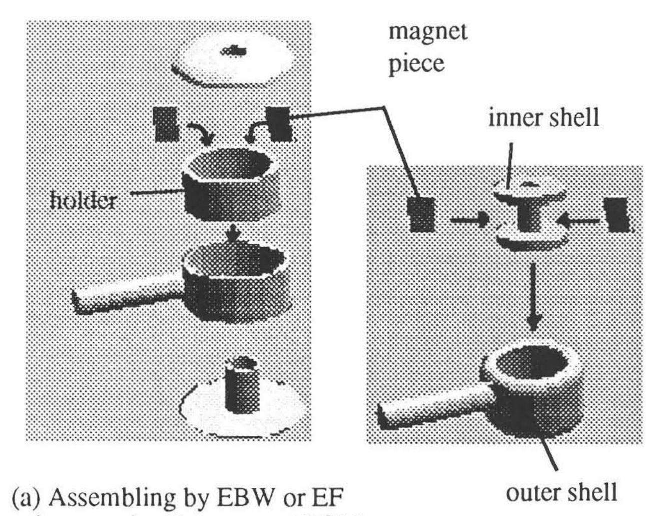
Drift-tube assembling

After assembling the PQM in the inner shell, the inner shell is inserted into the outer shell. The seams which join the inner and outer shells together must have the following functions, since the drift tube is set inside the evacuated DTL where a high-power rf field exists. They are as follows:
(a) a vacuum seal,
(b) rf and thermal contacts between the shells, and
(c) mechanical strength for the joint of the shells.

We examined three assembling methods of the drift tube:
(1) electron beam welding (EBW),
(2) electroforming (EF), and
(3) shrink fitting.

These methods were developed in close relation to the two PQM assembling methods described in the last section. Assembling of a drift tube with either EBW or EF was successful with a stainless steel drift tube [6]. In both cases the PQMs were assembled in a cylindrical holder. At present, both the EBW and the shrink fitting are under investigation for the copper drift tube, where the PQM is assembled directly in the inner shell.

Shrink fitting is of two types: cooling and heating. Details concerning the former were reported at the previous LINAC conference [5]. The latter uses hot water for expansion of an outer shell. The inner shell with the PQM is inserted into the expanded outer shell. The temperature of the outer shell is set as low as possible for the fitting, since a lower temperature is preferable in



(a) Assembling by EBW or EF using previously arranged PQM in a holder.

(b) Assembling by shrink fitting.

Fig. 4 Schemes of drift tube assembling.

order to set the jig accurately and to keep the PQM from deterioration.

For shrink fitting an important parameter is the degree of interference of the diameter of the shells. The increment of interference enhances the contacts pressure between the shells, resulting in good rf and thermal contacts and more stable vacuum sealing. However, shrink fitting causes stress in the drift tube which deforms its shape. The degree of deformation is roughly proportional to that of interference. The degree of the interference is still being investigated, since vacuum leaks of the order of 10^{-8} atm cc/s for He have sometimes been found from the seams of the drift tube assembled by shrink fitting.

The EBW method is being examined in order to assemble a copper drift tube; in this case the inner and outer shells are fitted by a heating shrink type fitting. Since shrink fitting precisely determines the position of the shells, EBW is easily carried out in order to join two shells together and to improve the quality of vacuum sealing. However, heat protection for the PQM must be considered, since the EBW increases the temperature of the drift tube. An EBW experiment was carried out in order to optimize both the electron beam current and setting the heat absorbers. The results showed no differences in the magnetic field strength and the position of PQM field center before and after EBW.

The surface of a drift tube is finished by buffing and electro-polishing (EP) after assembling of drift tube in order to reduce the micro juts made by the EBW, traces of the machining process and flaws on the drift-tube surface.

Drift tube alignment

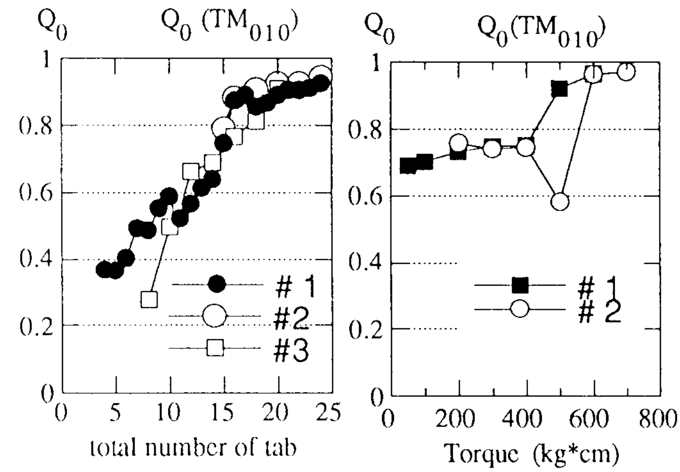
Since the drift tubes are mounted on the tank using a taper fitting, the head of the stem of the drift tube and the holes of the tank are both tapered off. Details concerning the fitting were reported at the previous LINAC conference [5].

A taper-type fitting ensures stable, strong, precise contacts between the stem and tank. However, the taper-type fitting has no adjustable mechanism for tuning the drift-tube position, except for the vertical direction within a range of about 100 mm. If the position of Q_0 is not exactly on the beam axis, the position of the drift tube must be corrected. For the horizontal direction the stem is bent, while the stem is extended in the vertical direction. The stem is deformed in the jig after removing the drift tube from the tank. Finally the vertical direction of drift tube is finely adjusted after the taper-type fitting by tuning the force used to pull up the stem.

Connecting adjacent unit tanks

A tank of the DTL comprises several short unit tanks. The surfaces of end-part of two adjacent unit tanks are directly connected in order to obtain good rf contact. It requires a fine control of a sufficient pressure on the surface, since there is no rf contactor, such as a shield fingers for rf contact.

We developed two types of connecting method: bolts connection and TIG welding with small tabs. The latter is used to join the first two unit tanks, since there is not sufficient space for the bolt connection between the tanks. The welding of small tabs produces the force to pull the unit tanks each other. The tabs are distributed around the DTL. This successfully results in good rf contact between unit tanks. We measured the Q-value of a short model tank which simulates the contacting region of the unit tanks. Figure 5 shows the results of a Q-value measurement; Fig. 5-a shows the results of the bolt connection; Fig. 5-b shows that of the welding. The abscissa of Fig. 5-b shows the torque tightened up each bolt. The Q-values are normalized by the calculated value. The vacuum seal is completed by another seal welding that is carried out before welding the tabs.



(a) TIG welding with tabs. (b) Bolt connection.

Fig. 5 Measured Q-values of the test cavity vs. contact pressure. The pressure is represented by either the number of tabs or torque. Q-values are normalized by the calculated value. The abscissa of 5-b shows the torque, tightening up each bolt. The number in the figures indicates the repetition of the experiment.

Conclusion

Construction of a high-power model of 432 MHz DTL is now in progress. Downsizing of the cavity due to increments of the resonant frequency required a investigation regarding the DTL construction method. New fabrication techniques for the model of the DTL were thus developed and examined.

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