NEW ENGINEERING TECHNIQUES USED IN A HIGH-POWER MODEL OF THE 432 MHz DTL

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Abstract

We have constructed a high-power model of the 432 MHz Drift-Tube Linac (DTL) using a number of new techniques which have been developed in order to achieve a higher long-term mechanical stability, a higher alignment accuracy, a higher cooling efficiency and better RF characteristics than those of conventional DTLs. A permanent quadrupole magnet was directly assembled within an inner shell of the drift tube. The inner shell was fixed in the outer shell by heat-shrink fitting, and both shells were assembled by electron-beam welding. The field centers of the magnet in the drift tube were converged on the mechanical center of the drift tube within about ± 20 μm. The drift tubes were accurately aligned on the beam line in the tank by a taper fitting and a plastic deformation of the stem. Satisfactory RF properties of the DTL were obtained in low- and high-power RF tests.

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) linac, a drift-tube linac (DTL) and a coupled-cell linac (CCL).

The resonant frequency (432 MHz) of the DTL is more than twice as high as a conventional 200 MHz DTL. Since the increased frequency reduces the size of the DTL, the dimensions of the 432 MHz DTL are so small as to allow the use of precision machining tools.

For constructing a high-duty, high-intensity DTL for practical use it is very important to take into account the following in order to obtain better RF properties:
(1) higher long-term mechanical stability,
(2) higher assembling and alignment accuracy,
(3) higher cooling efficiency of the components compared to those of conventional DTLs.

We have constructed a high-power model of the 432 MHz DTL in order to establish fabrication techniques to achieve the items described above. The high-power model of the DTL accelerates H^- ions from 3 to 5.4 MeV. It has 17 drift tubes and 8 post couplers installed in every other cell of the DTL. A photograph and a schematic view of the DTL are shown in Figs. 1 and 2, respectively.

The mechanical characteristics of the DTL are summarized below:
(i) Conventional DTLs are made with iron covered by copper. For improving the cooling efficiency, iron is not preferable because its

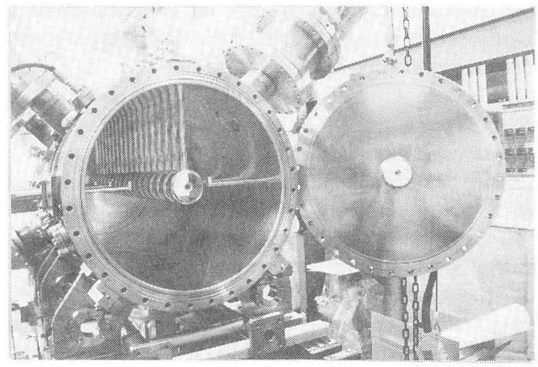

Fig .1 Photograph of the DTL.

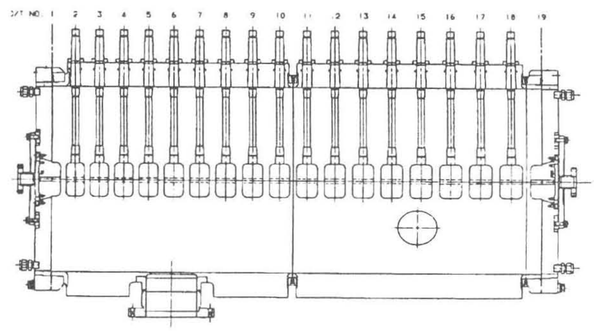

Fig .2 Schematic view of the DTL.

thermal conductivity is relatively low; we thus made the entire model of oxygen-free copper (OFC).
(ii) The DTL (1.2-m long) comprises two short unit tanks (about 0.6-m in length and 0.44-m in inner diameter), which allow us to mount drift tubes in the tank by hand. Moreover, high-precision instruments can be used for fabricating a tank, since the unit tank is sufficiently small to be placed on the instruments.
(iii) Two short unit tanks and the end plates directly contact without any RF contactor.
(iv) The unit tanks have tapered holes for the taper fitting of the drift tubes. The surfaces of the holes are finished by a high-precision numerical-controlled milling machine in order to fix the position of the tubes precisely and firmly.
(v) A permanent quadrupole magnet (PQM) is directly assembled in the inner shell of the drift tube.
(vi) The inner shell of the drift tube is inserted into the outer shell of the tube using a heat-shrink fitting. This method can fix the position of the PQM precisely. The seam of the heat-shrink fitting

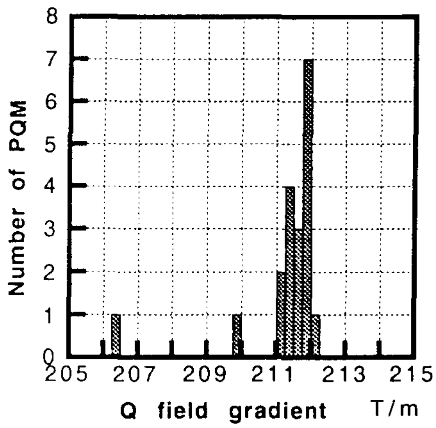

Fig.3
Distribution of the field gradient of the PQMs. The data were measured after EBW.

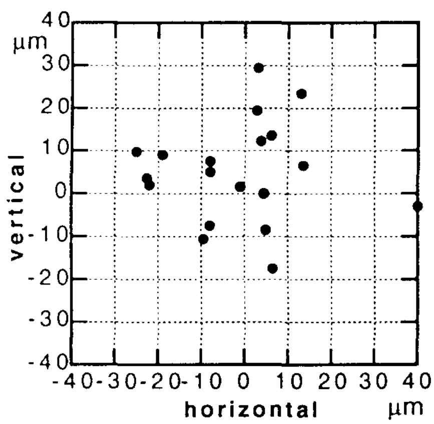

Fig.4
Position of the PQM field center measured after EBW. The origin of the axes is the mechanical center of the drift tube.

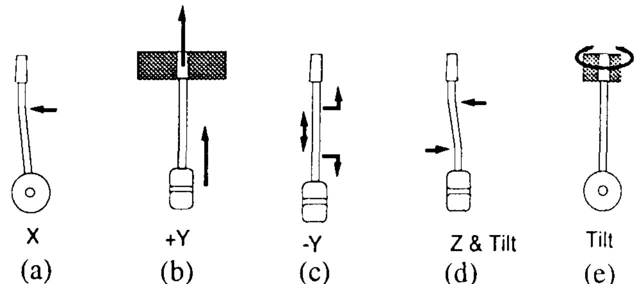

Fig.5 Schematic view of the stem deformation. The arrows show the action: (a) bend for the ±x direction, (b) pull for the +y direction, (c) extension for the -y direction, (d) double bend for the ±z direction & tilt in the y-z plane, and (e) rotation for tilt in the x-z plane.

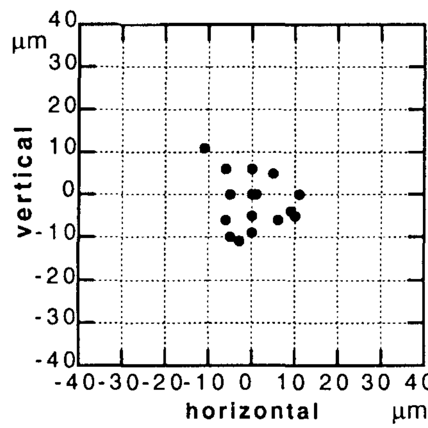

Fig.6
Position of the PQM field center after aligning the drift tubes in the tank. The origin of the axes is the beam line.

is completely sealed by electron-beam welding (EBW).

(vii) The drift tubes are aligned on the beam line using a plastic deformation of the stem, because a taper fitting method does not use a position tuning system, except for the vertical (+y) direction within a range of about 100 μm.

Details concerning the engineering techniques of the DTL have already been reported [2,3]. In this paper we report on the final results of construction using the new techniques. These correspond to the results of items (iv), (vi) and (vii) described above. The RF characteristics are described in reference [4].

Assembling a drift tube with a PQM

At a previous conference, we reported that we have tried three kinds of methods for assembling a drift tube with a PQM. These are: (1) electroforming (EF) of copper, (2) electron-beam welding (EBW) and (3) shrink fitting.

Finally, we assembled the drift tubes with PQMs using a hybrid method: The inner shell with the PQM was inserted into the outer shell by using a heat-shrink fitting method with a few μm interference of the diameter of the shells. Afterwards, an EBW was carried out in order to seal the seam of the fitting. During the EBW, we attached a copper cylinder to the drift tube in order to maintain the temperature of the tube at less than 110 °C. Because the surface of the drift-tube gap had a beaded pattern and craters made by the EBW, it was finished using a super-precise milling machine, which made the surface flat for avoiding any discharges on it, and adjusting the gap dimension. The flatness of the surface was a few μm.

The magnetic field center and field gradient of the PQM in the drift tube were measured both before and after the assembling of the drift tube. There was no discrepancy between the two data. The results of the measurements after assembling are shown in Figs. 3 and 4. The former is the distribution of the field gradient. The average field gradient is 211 T/m and the standard deviation of the distribution is 0.6%. The latter is the difference between the position of the tube mechanical center and that of the PQM field center. The PQM field center is defined as being the place where the dipole field measured by a rotating coil is minimum. The average of the differences is 17 μm, and the standard deviation is 9 μm. The accuracy of the measurement is about ± 10 μm.

Alignment of the drift tubes

The alignment of the drift tubes on the beam line is one of the most important processes in constructing a DTL. The PQM in the drift tube makes a dipole field on a beam axis, if the PQM field center (Q_0) is shifted from the axis. Since the beam is bent by the dipole field, the beam eventually becomes lost. The allowable alignment deviation in the DTL of the JHP is about ±30 μm. This is the target value for aligning the model.

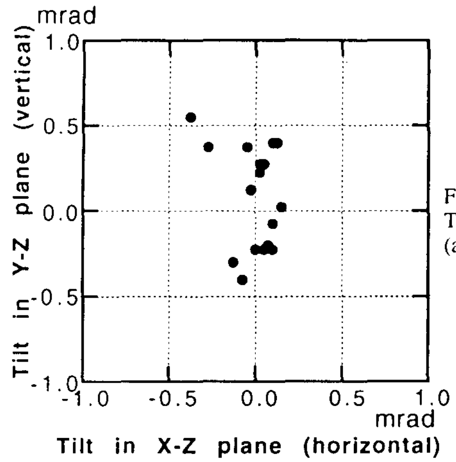

Fig .7
Tilt of the drift tubes. (after alignment)

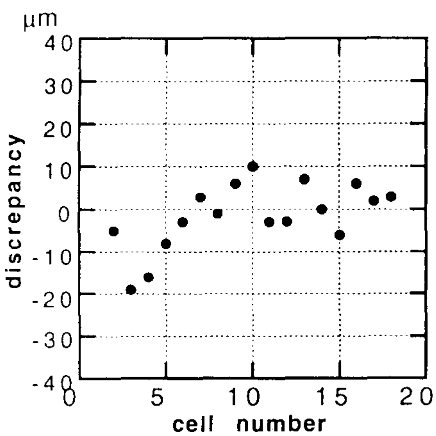

Fig .8
Differences in the Z-coordinate of the drift tubes from the design values.

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 [3]. The opening angle of the taper of the stem is 2.9 degrees and the taper is 55-mm long. The contact-area size is about 3500 mm^2. The surface of the tapered head of the stem has a chromium plate (50-mm width and 1 μm thickness) so as to avoid any merging of the surface materials together, and to increase the hardness of the surface. The strength of the force pulling up the stem was about 2600 N.

The position of the PQM field center (Q_0) was aligned on the beam axis by the plastic deformation of the stem. The stem-deformation method is schematically shown in Fig. 5. The tuning for the direction of the x, y and z axes is correlated with each other. Thus, we tuned the stems after studying the correlation in practice.

The position of the drift tube in the tank was measured by using two kinds of monitors. The longitudinal (z-axis) position and the tilt of the tube were measured by using a magnetic scale and four electrical linear gauges. The transverse position of the bore center was measured by using a target with an photodiode and a He-Ne laser system. The accuracy of each monitor was less than ± 10 μm. The total accuracy of our alignment was probably better than ± 30 μm.

Since the drift tubes contain PQMs, they attracted each other. After alignment of the tube, the attractive forces almost cancelled, because every tubes has neighbors at both sides, except for two half tubes in the end plates. However, during the alignment the tube that was being aligned had a neighbor at only one side. Thus, the stem was bent elastically by the magnetic force. We measured the degree of the bend as a function of the distance between the tubes before the alignment, and then corrected it in the case that the bend produced an error greater than 10 μm on the z-axis.

Figure 6 shows the Q_0 after the alignment. We calculated them from the measured point of the mechanical center of the drift tube. They are almost zero within the error. Figure 7 shows the tilt of the drift tubes. Figure 8 shows the deviation of the measured z-position from the design value. Both results show a sufficient accuracy of the alignment.

The accuracy of the alignment of the drift tubes reached the target value described above. The results show the status immediately after the alignment. We must therefore remeasure the whole position of the drift tubes in order to confirm the long-term stability in the future.

The average time required for aligning one drift tube was about 5 hours.

Conclusion

We have constructed a high-power model of the 432 MHz Drift-Tube Linac by using a number of new techniques which have been developed in order to achieve a higher long-term mechanical stability, a higher alignment accuracy, a higher cooling efficiency and better RF characteristics than those of the conventional DTLs. We assembled a permanent quadrupole magnet directly within an inner shell the of drift tube. The inner shell was fixed in the outer shell by heat-shrink fitting; both shells were assembled by electron-beam welding. The field centers of the magnets in the drift tube were converged on the mechanical center of the drift tube within about ± 20 μm. We accurately aligned the drift tubes on the beam line in the tank by a taper fitting and a plastic deformation of the stem. Satisfactory RF properties of the DTL were obtained by low- and high-power RF tests. The long-term mechanical stability will be tested in the near future. Simplification of the techniques by improving them is in progress for the next production of a DTL.

References

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