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題目(TITLE) Development of the DTL fot the JHP

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概要(ABSTRACT)

A low-power model for the 432 MHz DTL (Drift-Tube Linac) of the JHP (Japanese Hadron Project) has been constructed to study the rf properties. The best stabilization of an accelerating field was achieved by post couplers installed to every other cells in our case. The compact permanent (Nd-Fe) Q-magnets were fabricated precisely to match specifications that the beam dynamics demands. A prototype 5.4 MeV DTL is being constructed for the high power and beam tests.

KEY WORDS: Ion Source, RFQ, DTL, Magnet, Monitor, Beam Dynamics, Transport, Vacuum, Cooling, Klystron, Low Level RF, High Power RF, Modulator, Control, Operation, Radiation, Others

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DEVELOPMENT OF THE DTL FOR THE JHP

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Abstract

Experimental investigation for the development of the 432-MHz DTL is in progress with the aid of new engineering techniques with high accuracy. The required fabrication accuracy was tested with the construction of the low-power model of the DTL. The rf properties of the model in the low-ß region were studied. The field stabilization with post coupler was also studied by using the model and by the field patterns calculated with MAFIA. On the basis of the study of the low-power model, the high-power model of the DTL is being constructed for beam tests. The quadrupole magnets of high quality were fabricated.

Introduction

A 1-GeV high-intensity proton linac will be constructed 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 MeV to 148 MeV. A frequency of 432 MHz was chosen in order to increase the shunt impedance and to use stable klystrons.

The increase in the frequency reduces the size of the DTL. Thus, the precision machining tools can be utilized for a new fabricating method of the DTL. Therefore, a low-power model of the DTL was fabricated in order to test the accuracy both of machining and of assembling of the drift tubes. We also studied the rf characteristics, in particular, a stabilization of the field with post couplers. An analysis of the field pattern with MAFIA was applied to a DTL with post couplers.

A high-power model of the DTL is being constructed on the basis of the study of the low-power model. A permanent quadrupole magnet (PQM) is chosen for a focusing magnet because it is strong and compact. It requires neither the cooling nor maintenance. Assembling tools of PQM are also developed.

The low-power model of the DTL

The low-power 35-cell model of the DTL, 2.6 m in length, is divided into four unit tanks, that makes it easy to use precision machining tools. The drift tubes were held in the tank as shown in Fig. 1. The end part of the stem is tapered and fitted to a tapered hole on the tank. The taper section has two important functions; keeping good rf contact and aligning the drift tubes on the beam axis.

Since the cell length varies rapidly in the low-ß region, so does the effect of the stem on the cell frequency. The distribution of the frequency shift due to the stem is reduced by changing the diameter of the stem near the drift tube as seen in Fig. 1. Then, it was taken into account in the SUPERFISH calculation of the cell frequencies in order to obtain a flat distribution of an accelerating field. The field flatness thus obtained without post couplers was within 1.2%, where the accelerating field on axis was measured by a standard bead perturbation method.

The transverse deviations of drift tubes from the beam axis were 93, 28, 22 and 75 μm for four unit tanks, respectively. We found that the amount of the deviation among unit tanks depended upon manufacturing machines that made the taper section. It means that we can achieve the final goal of 20 μm with the aid of more precise machines for the machining of high-power model of the DTL.

Field stabilization with post couplers

An accelerating field in a DTL is distorted by some perturbations because of the zero group velocity of an accelerating TM_{010} mode. The perturbations will arise from thermal detuning, beam loading and structure imperfection. Post couplers are used for stabilizing the field against the perturbations by increasing the group velocity[2]. In general, a reduced number of post couplers are desirable as far as it is possible to keep the field stability because post couplers decrease the Q value. Thus, we studied the dependence of the field stability on the number of post couplers[3,4,5].

For discussing the field stability qualitatively it is useful for defining a distortion parameter[4] D by

$$D=\sum_{i=1}^{35}|E_i-\langle E\rangle| ,$$

where E_i is an average electric field of the i-th cell on axis normalized by the maximum electric field and $\langle E\rangle$ is an average of E_i's. A distortion parameter of 1.1×10^{-3} was obtained for the unperturbed field. A perturbation was intentionally introduced by inserting four frequency tuners. It gave rise to a 15% tilt of the field ($D=3.6\times10^{-3}$). If post couplers stabilize the field, the value of D will be reduced against the perturbation.

At first, thirty-four post couplers were inserted into the model. A fine, individual tuning of the length of each post coupler was required for stabilization of the accelerating field. The details of the tuning are described in Ref. 3. The distortion parameter of 1.5×10^{-3} was obtained on the stabilized condition. In order to study the effect of the number of the post couplers on the field stability we attempted to reduce the number of post couplers (17, 12, 6, 4, and 3 post couplers). The field stabilization was observed except for the case of three post couplers.

A group velocity of the accelerating mode, defined as a derivative of the measured dispersion curve, is another measure of the stabilization effect[5]. It can be seen from Fig. 2 that the group velocity with 34 post couplers is approximately equal to that with 12 post couplers. The maximum group velocity was obtained with 17 post couplers. On the other hand, the Q value decreases with increasing the number of post couplers; about 7% decrease by inserting 34 post couplers, which is not negligibly small. It is thus concluded that the optimum number of post couplers for the model is 17, compromising between the obtained group velocity and the decrease in the Q value.

The analysis of field patterns with MAFIA

The stabilization with post couplers was introduced on the analogy of a π/2 mode CCL[2]. Properties of the stabilization were explained from calculations of an equivalent circuit[6,7]. The computer code MAFIA[8] was used in order to study field patterns of the TM and the post modes of a DTL with 7 cells and 6 post couplers. The input geometry with 1.8×10^5 meshes is prepared as shown in Fig. 3. Both accelerating gap and the size of the drift tube are kept constant for the simplicity. The calculated dispersion curve is shown in Fig. 4. Among these modes, both nearest neighboring modes of TM_{010}, the TM_{011} mode and the post mode PC_1, play an important role in the stabilization effect. Here the PC_1 is the highest among the post modes. The electric field Ez on the beam axis is shown in Fig. 5 both for the TM_{011} and for the PC_1 mode. It can be seen that the Ez of TM_{011} and PC_1 have a node in the center of the DTL. Figure 6 shows the E vector in the y-z plane including a beam axis. Figures 7 and 8 show the E and H vectors in the z-x plane below the drift tubes. The patterns of these vectors show the following facts. (1) The field of TM_{011} is distorted by the stems as seen in Fig. 6-a. It contains a TE-like field pattern because it has the loop of the magnetic field in the z-x plane as seen in Fig. 8-a. (2) The field pattern of TM_{011} below the drift tubes resembles that of the PC_1 as seen in Fig. 7. (3) The Ez of TM_{011} mode and PC_1 have an opposite sign of tilt if TM_{011} mode has the same phase as PC_1 mode in the lower half of the DTL.

The Ez of TM_{010} mode is stabilized mainly by the contribution from TM_{011} and PC_1. However, the result of MAFIA suggests that Ey's of both modes on the beam axis are not compensated. Instead, Ey's are enhanced when Ez's are compensated. The strength of Ey depends on the situation of the stabilization and the design of DTL. The maximum values of Ey both of TM_{011} mode and of PC_1 mode are about 5% of Ez. The maximum value of Ex of the TM_{011} mode is less than 1% of Ez, while that of PC_1 mode is about 3% of Ez in the above calculation.

The high-power model of the DTL

The high-power model of the DTL, 1.2 m in length and 0.44 m in diameter, is being constructed on the basis of the study of the low-power model. The DTL, made of an oxygen-free copper (OFC), accelerates the H^- beam from 3-MeV to 5.4-MeV. It has 18 cells and

2 unit tanks. The post couplers are installed in every other cell of the model.

The following new problems related with a new fabrication method should be solved before the construction of the high-power model; (1) assembling of adjacent two unit tanks, (2) assembling of drift tubes, (3) seal of drift tubes containing quadrupole magnets in the drift tube, (4) fabrication of compact and strong permanent magnets, and (5) development of an input coupler. The assembling method of the drift tube is shown in Fig. 1. It has three functions; an rf contact, a position alignment of the drift tube and a vacuum seal. There are three kinds of method of the seal of the drift tube. They are the electron beam welding (EBW), the electroforming (EF)[9] and the cold shrinking method[10]. The developments of EBW and EF have been done successfully. The cold shrinking method is now under development. An input coupler was designed[11] with the aid of the computer codes, SUPERFISH and MAFIA.

The permanent quadrupole magnet

Specifications of the quadrupole magnet required from the beam dynamics are as follows. (1) The integrated field is 5.5 T for 3-MeV H^- injection in order to obtain a transverse phase advance of about 60 degrees. It requires a gradient of the magnetic field of 184 T/m with a magnet length of 30 mm. (2) The deviation of the quadrupole field center from the beam axis is about 20 µm (r.m.s.). (3) The variation of the field gradient is within ±4.4%.

The Nd-Fe-B permanent magnet that satisfies the specification (1) was chosen for making the quadrupole magnet. Figure 9-a shows a cross section of the quadrupole magnet, that is composed of 16 segments with five kinds of directions of magnetization[12]. The segments with three kinds of axis of magnetization were made as shown in Fig. 9-b. The specification (2) requires the high accuracy of the fabrication for each segment. The calculation with the computer code PANDIRA[12] gave the displacement of the center of quadrupole field with two kinds of perturbation for three kinds of segment. Results are summarized in Table. I.

Table. I
Displacement of Quadrupole Field Center

Perturbation for a segment	PANDIRA Displacement of field center (µm)	Types of segments
Deviation of magnetization of 1%	3	0°
	< 5	45°
	5	90°
Deviation of direction of magnetization of 1°	5	0°
	2	45°
	8	90°

The deviations of the field strength and the direction of magnetization from the designed values must be less than ±0.4% and ±0.3° respectively in order to obtain the specification (2) mentioned above. The fabrication of the segments was carefully carried out in order to achieve the required accuracy. The accuracy thus obtained are shown in Table. II. The magnetic field of the two sets of PQM's was measured by using a rotary coil. The deviations of the quadrupole field centers from the mechanical center of the PQM were 25 and 8 µm respectively with the experimental error of about 10 µm. Since the segments of permanent magnet were assembled into the PQM without a shuffling, the measured deviations were small enough to meet the requirement within the error.

Table II
Accuracy of Test Segments of Magnet

Types of segments	Deviation from the designed value (degree)	Standard deviation of the field strength (%)
0°	0.2±0.2	0.3
45°	0.7±0.3	0.2
90°	0.2±0.2	0.2

Conclusions

The development of the DTL for the JHP is in progress with the aid of new engineering techniques with high accuracy. The accuracy of the fabrication was tested by means of the construction of the low-power model of the DTL. The rf properties of the model in the low-ß region were also studied. The stabilization of an accelerating field by post couplers was confirmed. The number of post couplers was optimized. The field patterns of a DTL with post couplers were studied with MAFIA. The high-power model of the DTL is under construction. The quadrupole magnets of high quality were fabricated.

Acknowledgment

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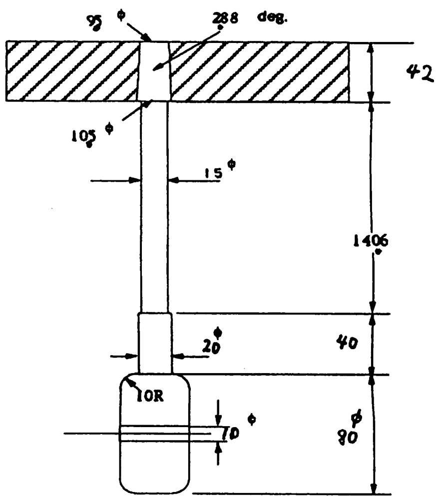


Fig. 1. Drift Tube and Stem.

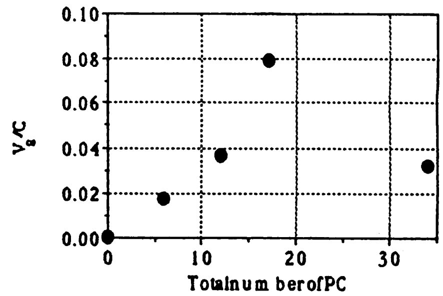


Fig. 2 Group velocity vs. total number of post couplers.

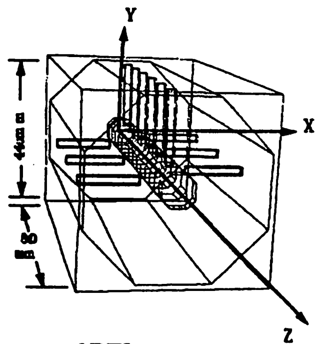


Fig. 3 Input geometry of DTL.

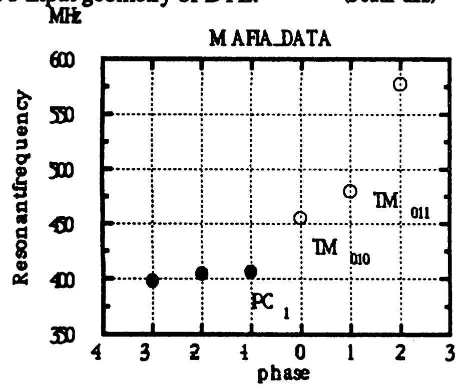


Fig. 4. Dispersion curve of TM_{01} and post modes calculated with MAFIA.

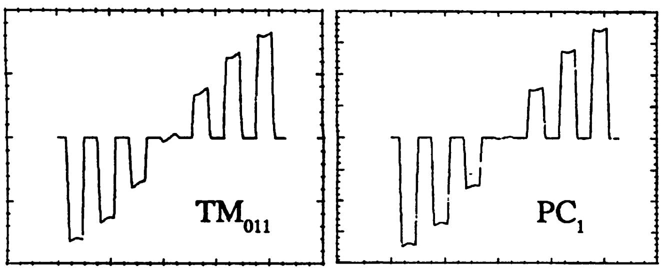


Fig. 5. z component of the electric vector on beam axis.

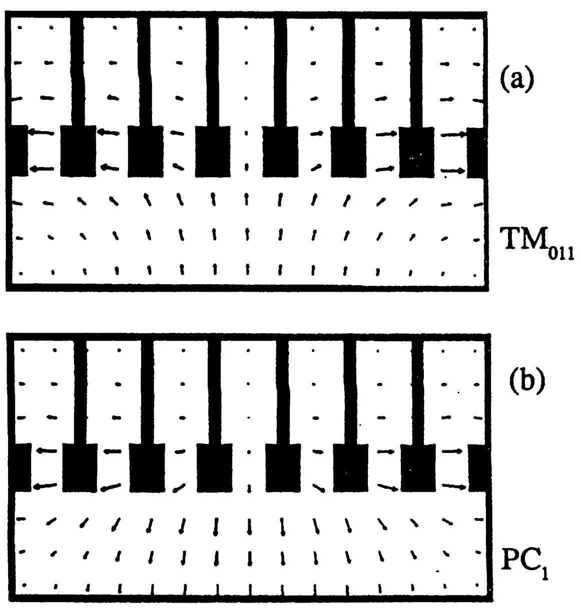


Fig. 6. Electric vectors in y-z plane included beam axis.

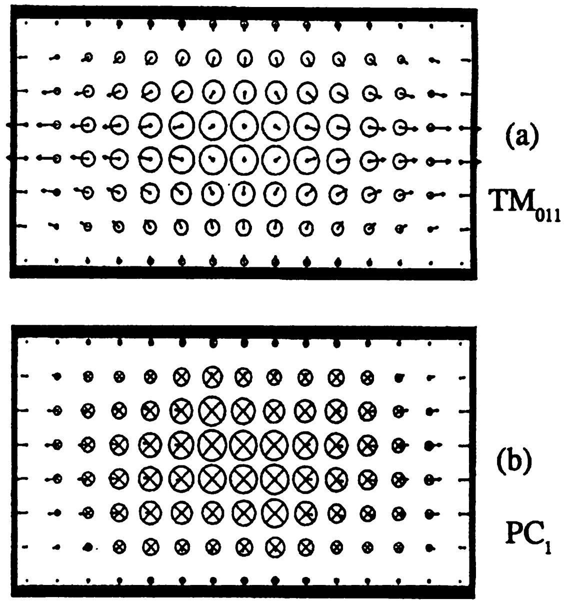


Fig. 7. Electric vectors in z-x plane below drift tubes.

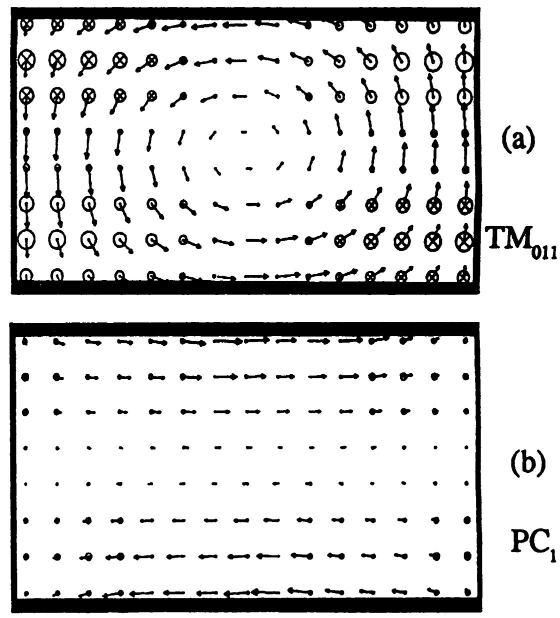
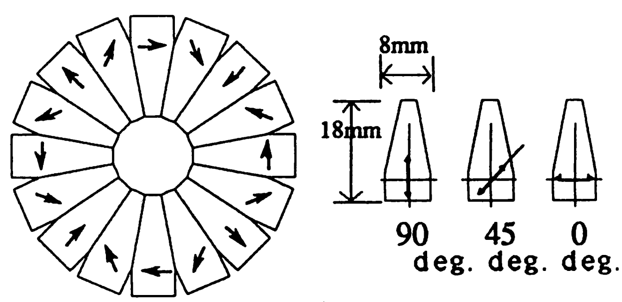


Fig. 8. Magntic vectors in z-x plane below drift tubes.



(a) Cross section of PQM. (b) Direction of magnetization.

Fig. 9. Parmnent Quadrupole Magnet.