# DEVELOPMENT OF THE 1 GeV PROTON LINAC FOR THE JAPANESE HADRON FACILITY

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## Abstract

Present status of development of the 1 GeV proton linac for the Japanese Hadron Project is reported. Electroforming method to seal a 432 MHz drift tube was developed. Results of field measurement are presented for a cold model of a drift-tube linac. Study of an annular-coupled structure indicates that the structure is promising for the project.

## Introduction

The 1 GeV proton linac will be constructed to inject negative hydrogen beams to the ring accelerator for the Japanese Hadron Project (JHP)[1]. The linac is composed of a volume production type $H^-$ ion source, a 432 MHz RFQ linac (3MeV), a 432 MHz drift-tube linac (148MeV), and a 1296 MHz high-$\beta$ linac (1 GeV). Detailed design parameters of the linac are presented in Refs. 2-5 together with rationale for the chosen parameters. Results of recent development of high power RF sources are reported in a contributed paper of this conference. In the present paper our development of the drift-tube linac (DTL) and the high-$\beta$ linac will be described.

## Drift-tube Linac

The 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 Refs. 2 and 6. Permanent quadrupole magnets such as SmCo and Nd-B-Fe will be used, since they require neither of electric 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 high temperature during silver brazing and strong magnetic field of the permanent magnets bends the electron beam for electron-beam welding (EBW).

Thus, an electroforming method has been developed to seal the drift tubes from vacuum, since the electroplating is possible at room temperature. A bad influence of the magnetic field on quality of the electroplating could be eliminated by taking a special care for flow of electroplating fluid. Positions where drift tubes made of stainless steel were copper-electroplated are shown in Fig. 1. A drift tube and Nd-B-Fe permanent quadrupole magnet shown in Fig. 2 were assembled and electroformed as shown in Fig. 3. During an electroforming process any leakage of the electroplating fluid should be prevented to keep the permanent magnet from erosion. Thus, very fine machining of contact surfaces was necessary.

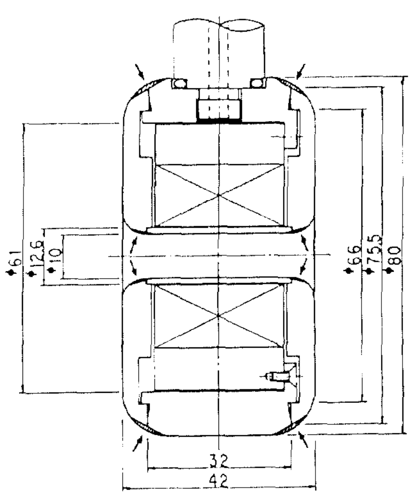


Fig. 1. Positions of electroforming of a drift tube.

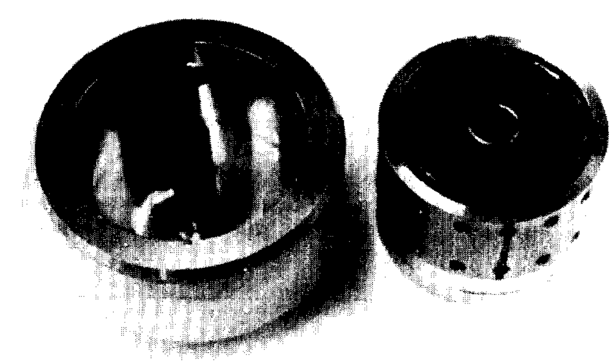

Fig. 2. A drift tube and permanent quadrupole magnet before assembled.

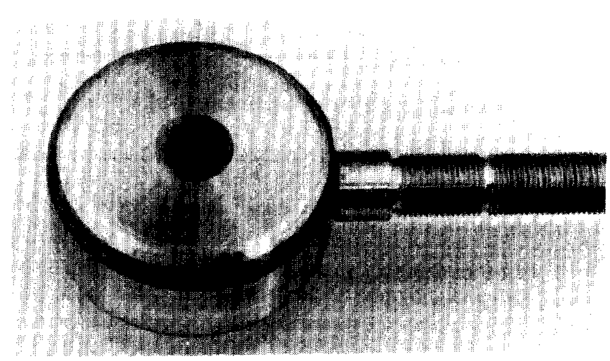

Fig. 3. A drift tube sealed with the electroforming method.

An electron-beam welding of drift tubes with the permanent magnets was also attempted by shielding the electron beam from the strong magnetic field. Distortion of the electron beam orbit could be reduced to less than 1mm. A method of insulation of the permanent magnet from heat input of the welding was developed, resulting in the highest temperature of 65°C on the permanent magnet. This temperature will be tolerable even by the Nd-B-Fe magnet. Thus, in near future we have to determine which method is more suitable for mass production of the drift tubes between the electroforming and EBW.

A cold model (3 MeV to 8 MeV, 35 cells, 2.6 m) made of aluminum for half of the first DTL tank has been fabricated to obtain necessary data for final detailed design. We have chosen a flat-field type rather than a gradient-field type for reasons described in Ref. 3.

Prior to installing post couplers field distribution was measured throughout the tank as shown in Fig. 4. It is seen that fairly good field flatness was already obtained. Here, it is noted that beta

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dependence of effect of stems was corrected by adjusting gap lengths between the drift tubes to make frequencies of all cells uniform. Field tilt was produced by frequency tuners as shown in Fig. 5. Then, distances between the drift tubes and post couplers with tabs were adjusted to eliminate the field tilt as seen from the same figure. The field flatness without the perturbation was also improved by the post couplers as shown in Fig. 4. The uniformity of the cell frequencies is preferable to minimize a mixing of post modes to an accelerating mode[7], although the post couplers are useful to stabilize the field distribution against beam loading and wall loss as well as manufacturing imperfections.

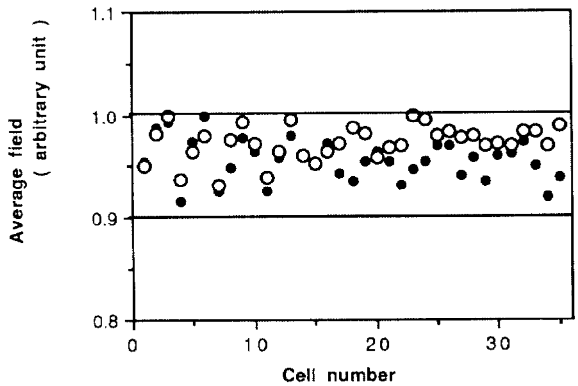


Fig. 4. Distribution of average accelerating field among cells of a cold model of the DTL. Data without post couplers are designated by solid circles, while those with post couplers by open circles.

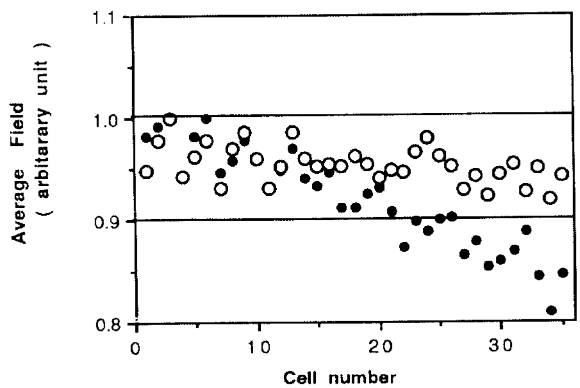


Fig. 5. Effect of detuning on the field distribution. Designation of the solid and open circles is the same as Fig. 4.

The cold model was also used to test fine alignment of drift tubes. It will be necessary to align symmetric axes of the quadrupole magnetic fields within a few ten µm to the beam axis. We are attempting to obtain this accurary with an extremely fine machining, that is, without adjustment mechanism. Although the first attempt was far from satisfactory (about ±0.1mm), we are still developing a high-precision machining, since this method will be advantageous for mass production and long-term mechanical stability.

## High-$\beta$ Linac

Standing wave linacs are more advantageous than traveling wave linacs, if RF pulse widths are longer than filling times. The $\pi/2$ mode operation of a multi-cell cavity is necessary to keep a high degree of stability of the accelerating field against effects due to heavy beam loading and manufacturing imperfections. Then, possible candidates for the high-$\beta$ cavity structure are alternating periodic structure (APS)[8] or on-axis coupled structure (OCS), side-coupled structure (SCS)[9], disc-and-washer structure (DAW)[10] and annular-coupled structure (ACS)[11].

For the ACS it was reported that serious depression of a quality factor is arising from excitation of a coupling-cell quadrupole mode[11]. In the DAW a passband of a deflecting mode crosses the accelerating frequency. A method to keep the passband of the deflecting mode away from the accelerating frequency decreases its shunt impedance seriously[12]. Therefore, we have been developing manufacturing techniques for the APS and SCS as reported in Refs. 2-5. The axial symmetry of the APS has potential advantage of mechanical simplicity and beam stability over the axially asymmetric SCS. However, a shunt impedance of the APS is lower than that of the SCS, since coupling cells of the APS are located on the beam axis consuming space for accelerating cells. The shunt impedance of the APS is about 55 to 80 percent of that of the SCS depending upon the values of $\beta$=v/c. Thus, we have not yet determined which structure is more preferable for the JHP.

In this context the ACS became attractive with its symmetric structure as shown in Fig. 6. Thus, we again investigated the reason of the serious depression of the quality factor of the ACS reported in Ref. 11. It is noted that the accelerating mode in an ideally periodic structure should not excite any mode in coupling cells other than the modes with the open boundary condition at the centers of the coupling cells. Thus, we reasoned that the excitation of the quadrupole mode in the coupling cells reported in Ref. 11 was arising from some kind of asymmetry, probably, induced by alternately located two coupling slots. (This reasoning was actually confirmed[13].) In this way we began to improve the shunt impedance of the ACS[14].

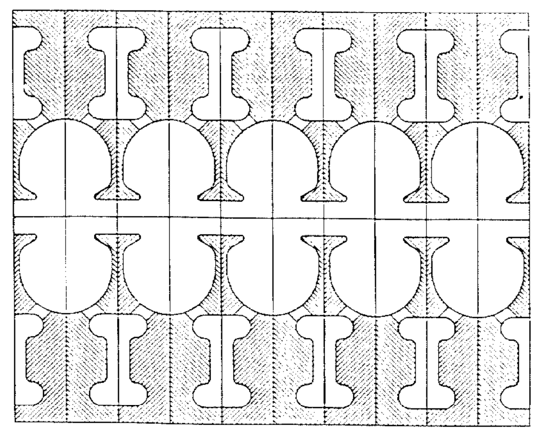

Fig. 6. Cutaway view of the annular-coupled structure.

Examples of half-size models used in our study are shown in Fig. 7. A computer program MAFIA[15] was used to understand experimental results qualitatively. Measured coupling coefficients in the case of four coupling slots are plotted versus a slot arc length in Fig. 8. Measured quality factors are shown in Fig.9 as divided by that of a single cell without coupling slots. Striking feature of the four coupling slots is that the dipole and quadrupole modes in the coupling cells are situated at higher frequencies than the passband of the accelerating mode.

We have also studied cases of two coupling slots and eight coupling slots. In the former case the dipole mode of the coupling cell was lowered down to the passband of the accelerating mode as already reported in Ref. 16. In the latter case it was hard to obtain four or five percent coupling, if the wall thickness between the accelerating and coupling cells is practically possible to be constructed.

The reduction of the quality factor of the ACS with the four coupling slots as compared with that of the single cell is arising from interference of large coupling slots with the flow of the electric current at the surface of the accelerating cell rather than the excitation of the quadrupole mode in the coupling cell. Since the volumes of the coupling cells of the ACS are generally much larger than those of the SCS, the apertures of the coupling slots have to be larger than those of the SCS with the same coupling coefficient, giving rise to larger reduction of the quality factor of the ACS.

However, only 10 or 15 percent inferiority of the quality factor of the ACS to that of the SCS will be compensated by the potential advantage of the symmetric structure of the ACS. Therefore, we will continue to develop the ACS as one of the most promising structures for the JHP.


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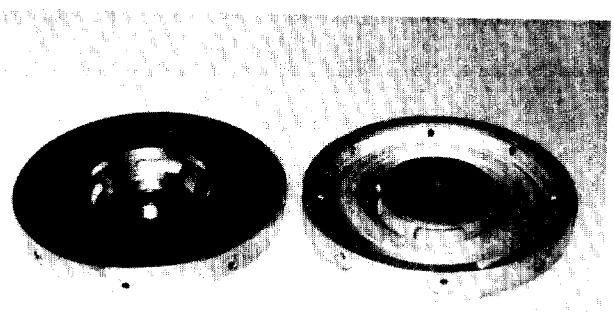

Fig. 7. Half cells of the annular-coupled structure. (Half-size model).

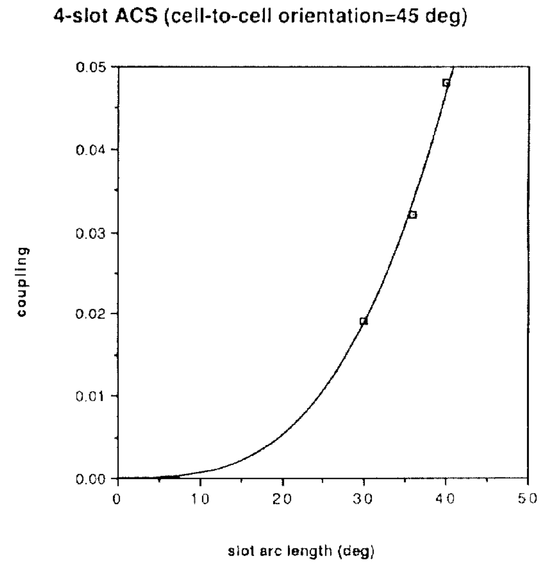


Fig. 8. Dependence of a coupling coefficient on the coupling slot arc length in degree ($\beta$=0.8). Number of slots is four, and a width of the slots and a wall thickness correspond to 18mm and 10mm, respectively, for the 1296 MHz structure.

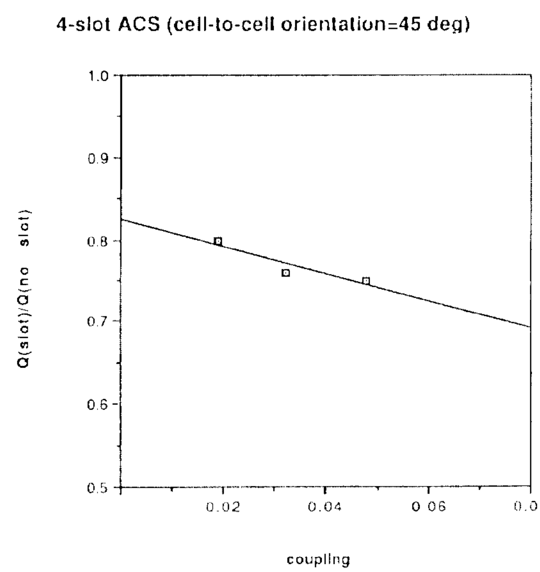


Fig. 9. Dependence of the measured quality factor of the accelerating mode on the coupling coefficient. The quality factor is shown as divided by that of a single cell.