IMPROVEMENTS OF RF CHARACTERISTICS IN THE SDTL OF THE J-PARC PROTON LINAC

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Abstract

A separated drift tube linac (SDTL) was adopted as an accelerating structure of Japan Proton Accelerator Complex (J-PARC), which follows the DTL. The SDTL of J-PARC consists of 32 five-cell short tanks, ranging from 1.5 to 2.5 m in length. A design of frequency tuners of the SDTL was performed by taking account of 3-D field distribution calculated with MAFIA. The effects of stems on the resonant frequency and field distribution were also analyzed. An easy and effective compensation method for perturbation by stems of both end cells was proposed and applied to the SDTL tanks.

INTRODUCTION

An Alvarez drift-tube linac (DTL) is widely used for accelerating low-energy proton beams. It is a complicated and sophisticated structure since drift-tubes contain focusing magnets. A separated-type drift-tube linac (SDTL) was proposed [1] as an accelerating structure for the medium-energy region because of both high shunt impedance and ease of construction. Higher shunt impedance can be realized by eliminating focusing devices from drift tubes. Instead, the focusing elements are placed between two adjacent SDTL tanks. Since one of the merits of the SDTL structure is simplicity of both rf properties and mechanical issues in construction, any kinds of stabilizing devices (post couplers or multi-stems) are not usually installed. Thus, the number of cells in a tank is also important from the viewpoint of rf stabilization.

The SDTL was adopted as the accelerating structure of J-PARC linac [2], which connects the DTL and the ACS. The SDTL of J-PARC consists of 32 short five-cell tanks. A normal unit cell in the tank consists of an accelerating gap, two tubes of half-size and two half stems. Table 1 shows the parameters of the SDTL tank.

Table 1. Parameters of SDTL tank for J-PARC

Frequency	324 MHz
Tank diameter	520 mm
Drift tube diameter	92 mm
Stem diameter	36 mm
Cell length	0.29– 0.51m
Tank length	1.47 – 2.56m
Energy	50 – 190 MeV

As the first constructed SDTL linac in the world, the tuner of the SDTL was designed based on the detailed calculation by using MAFIA. The special attention should be taken for both end cells, where there is no half stem on the end plate usually. An easy and effective compensation method for the perturbation of the stem to the accelerating field was studied by the simulations.

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THE DESIGN OF THE TUNER

The Positions for Installing Tuners

As shown in Table 1 for J-PARC, the maximum length of SDTL tanks is 2.56 m, and the number of the tuner is expected within three. Fig.1 shows the sketch of a five-cell SDTL tank and the candidate positions for tuners in the longitudinal direction.

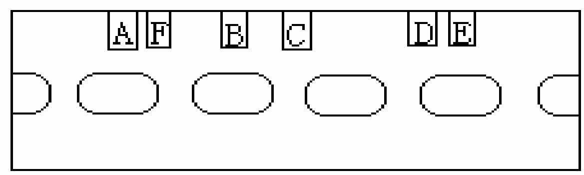

Figure 1: The sketch of a five-cell SDTL tank and the candidate positions (A~F) for tuner in the longitudinal direction.

In case of adopting 3 tuners, there are two choices for the distribution of tuners in the longitudinal direction. One choice is installing in the positions of F, C and D, in which C is in the center of the tank, and F and D are at L/4 from the both end plates respectively, with L the length of the tank. In this case, the distribution of the tuner is uniform in longitudinal direction, but all the tuners are not located in the center of the tube, where is the most effective tuning position. The other choice is installing in the positions of A, B and E, with A, B and E the center of the drift tube, but in this case three tuners are not regularly distributed in the longitudinal directions. To decide the distribution of the tuner, the simulations were made by MAFIA, for investigating the difference of the tuning efficiency among different positions. For all SDTL tanks, the diameter of the tuner was chosen as 90 mm.

Fig. 2 shows the simulated frequency shift of one tuner with different insertion length for different positions in the 97-MeV tank. For the insertion length more than 5 cm, the tuner positioned at A is much more effective than tuners positioned at the other two places. The power losses on the tuner surface at different positions were almost equal.

According to the simulation results, the tuners should be positioned at the position of the center of the drift tube in longitudinal direction. In case of installing three tuners, the positions should be A, B and E. Another reason for selecting mid point of the drift tube for tuner position is that the positions of F, C and D are located at the gap-center or near the gap-center, and in this case, the total frequency shift decreases rapidly as the tank length increases. Therefore, for the 2.5 m (190-MeV) tank, a three-tuner system of gap-center tuner position does not work well.

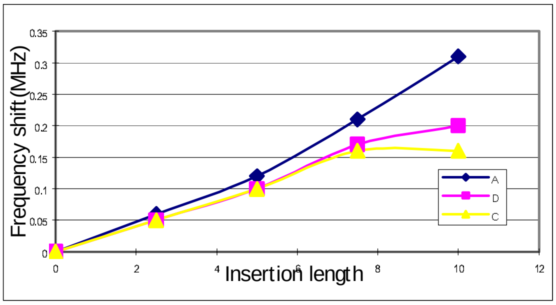

Figure 2: Frequency shift vs. different insertion length for different longitudinal positions.

Tuning Effects for Different Number of Tuners

Figure 3 shows the simulated tuning effects vs. different number of tuners at 97-MeV tank. One tuner is positioned at A, two tuners are positioned at A and its symmetric position E, while three tuners are positioned at A , E and B. The total tuning effect is proportional to the number of tuners. The final number of tuners installed in each tank should be determined by the requirement of the tuning ability (a range of frequency shift and the deviation of the field distribution).

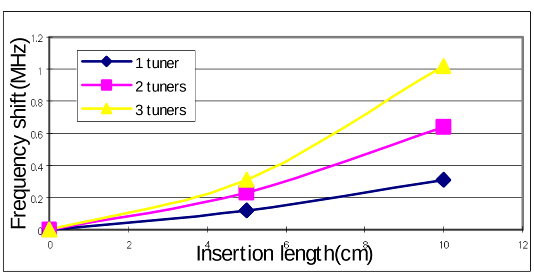

Figure 3: Frequency shifts vs. different insertion length for the different number of tuners.

Tuning Effects for Different Tank

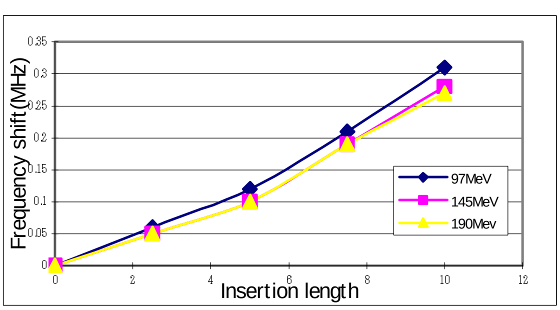

Figure 4: Frequency shift vs. different insertion length for different tank.

To compare the tuner effect for different tanks with the same tuner diameter, simulation was done with one tuner. One tuner was positioned at position A. Fig. 4 shows the tuning effects for different tanks. With the same diameter of tuner, the tuning ability was decreased with the increase in the length of the tank, but the decrease in the tuning ability was within 10%. Therefore, the tuner of the same size can be adopted for all SDTL tanks.

Tuning Effects for Different Angle From Stem

The simulations were done for comparing tuning effects with 45° and 60° angles between the tuner and the stem. The small angle means the tuner is much close to the stem. The insertion length is fixed to 7.5cm, and only one tuner at position A is used. Table 2 indicates that for the 45° and 60° angles between the tuner and the stem, the tuning effects are equal, and the power losses on the surface of the tuner are also nearly equal. In table 2, the values of power loss and E were the relative values to that of the 60°. To save the space in the tunnel, 45° angle between tuner and stem was chosen.

Table 2. Some results for different angles

	45°	60°
Tuning effect	0.21MHz	0.20MHz
Power loss on the surface	0.99	1
Ez at top surface of the tuner	0.99	1
Er at top surface of the tuner	0.56	1

The simulation shows that when the insertion length was more than 10cm, the increased tuning effect for frequency was very small, and the additional mode would be induced. The maximum insertion length of tuner should be 10 cm.

COMPENSATION FOR THE FIELD PERTRUBATION INDUCED BY STEMS

There are two special end cells in the SDTL tank, where there is no half stem on the end plate usually. The design field distribution is uniform in a SDTL tank, but the uniform distribution would be deformed because of the lack of the half stem at the end cell. Fig. 5 shows the simulated field distribution of the first SDTL tank without end cell compensation, in which the deviation of the field distribution was 1.7%. Taking the advantage of the near symmetry of the geometry in the longitudinal direction, simulation was made for the half SDTL tank.

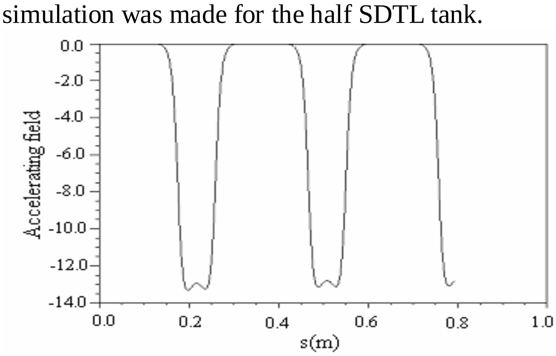

Figure 5: The simulated field distribution of the first SDTL tank without end cell compensation, made by MAFIA.

To compensate the stem effect, a direct method is using a half stem at each end plate, but this simple method becomes complicated in fabrication. An easy and effective compensation method for the perturbation of the stem to accelerating field was proposed [3]. A thin circular disk was added on the end plate instead of a half stem: a thickness and a radius of the disk was chosen so that a frequency shift due to the increase in the volume of the end plate may be equal to that of the virtual half-stem on the end plate. In order to keep the cell length and the gap length, the outer radius of the disk was less than the radius of the tank. The inner radius of the disk was selected to be the same as the radius of the drift tube because of ease of fabrication.

For studying the effect of the compensation, some simulations were made for the first SDTL tank by using MAFIA. The simulated accelerating field distribution without end-cell compensation is shown in Fig. 5, and the corresponding simulation results with compensation by adding a thin circular disk on the end plate is shown in Fig. 6, in which the thickness of the disk was 1.5 mm and the radius of the disk was 250 mm. It shows that, the field deviation was perfectly compensated, and field distribution became uniform in the simulation. The effect of the compensation with a disk of 1.5 mm in thickness was equal to that by adding a half stem on the end plate, as shown in Fig.6. When a disk of 1.0mm in thickness was used in the simulation, the deviation of the field distribution was 0.58%, as shown in Fig.7, which was still within the tolerance (±1%).

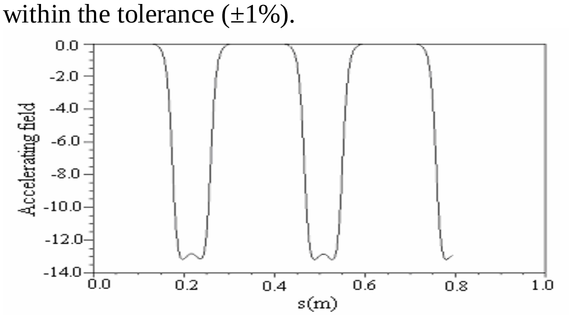

Figure 6: Simulated field distribution in the first SDTL tank with compensation by adding a thin circular disk at the end plate. The thickness of the disk was 1.5 mm and the radius of the disk was 250 mm

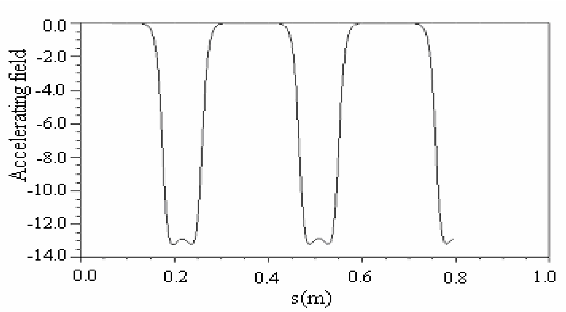

Figure 7: Simulated field distribution in the first SDTL tank with compensation by adding a thin circular disk at the end plate. The thickness of the disk was 1.0 mm and the radius of the disk was 250 mm

PERTURBATION OF THE TUNER TO THE FIELD DISTRIBUTION

The perturbations of the tuner to the field distribution were studied by simulation for the 50-MeV tank. Fig. 8 shows the MAFIA model used in the simulation, in which there are two circular disks at the end plates. The thickness of the disk was 1.5 mm and the radius of the disk was 250 mm, and the insertion length of the three tuners were all 7.5 cm. As shown in Fig.6, the field distribution was uniform without tuner. With the perturbation of the tuners, the field distribution is shown in Fig. 9, the deviation of the field distribution was ±0.8%.

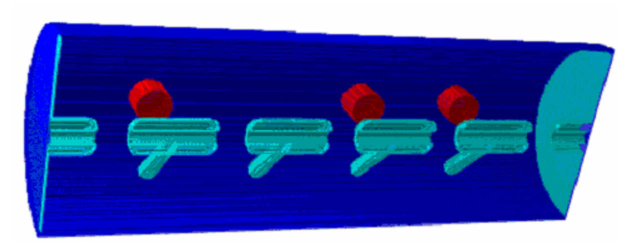

Figure 8: MAFIA model with tuners and circular disks

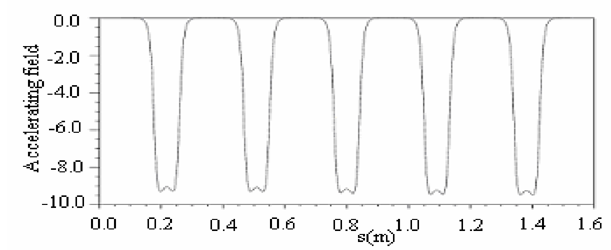

Figure 9: The field distribution of the 50-MeV SDTL tank with tuners and circular disks

CONCLUSION

The tuner of the SDTL tank of J-PARC was designed based on the detailed calculation by using MAFIA. The tuner should be positioned in the center of the tube at longitudinal direction, instead of symmetric assembly; with 45° angle from stem; the maximum insertion length of the tuner should be not larger than 10cm; for all SDTL tanks, the tuner of the same diameter could be used. An easy and effective compensation method for the perturbation of the stem to accelerating field was studied by the simulations. It shows that with a disk of 1.5 mm in thickness and 250 mm in radius adding to the end plate, the field distributions were correctly adjusted.

REFERENCES

[1] T. Kato, Proposal of a Separated-type Proton Drift Tube Linac for a Medium-Energy Structure. KEK Report 92-10 (1992).

[2] JHF Project Office, "JHF Accelerator Design Study Report", KEK Report 97-16 Chapter 4 (JHF-97-10), 1998, Accelerator Technical Design Report for J-PARC, KEK Report 2002-13 (2003).

[3] T. Kato et al., Compensation for the Stem Effects of the End Cells for the J-PARC SDTL Structure, to be published in KEK Report.