RF CHARACTERISTICS OF A HIGH-POWER MODEL OF THE 432MHz DTL

F. Naito, S. Anami, Z. Igarashi, T. Kato, M. Kawamura, T. Kubota, T. Kubo, K. Kudo, Y. Morozumi, K. Nanmo, M. Ono, E. Takasaki, T. Takenaka, K. Yoshino and Y. Yamazaki
KEK, National Laboratory for High Energy Physics
1-1 Oho, Tsukuba-shi, Ibaraki-ken, 305 JAPAN

Abstract

We have constructed a high-power model of the 432-MHz Drift Tube Linac (DTL) for the Japanese Hadron Project. Since the DTL was accurately fabricated using new engineering techniques, we obtained adequate RF characteristics. The Q value of the DTL is high sufficient, showing that a method of direct RF contact without any RF contactor between unit tanks and between the unit tank and an end plate of the DTL is also adequate. The distribution of the accelerating field of the DTL is sufficiently uniform without using a post coupler because of the accurate alignment of the drift tubes. Furthermore, the accelerating field was stabilized by using post couplers against any perturbations. A high-power test of the DTL was carried out up to about 1.2-times the design value without any trouble. A coaxial input coupler with a disk-type ceramic window fed the high-power RF into the DTL successfully.

Introduction

We have constructed a high-power model of the 432-MHz drift-tube linac (DTL) at KEK for the 1-GeV proton linac of the Japanese Hadron Project (JHP). The 1-GeV linac is being considered as an injector for a ring accelerator of the JHP. The 1-GeV linac comprises a radio-frequency quadrupole (RFQ), a drift-tube linac (DTL) and a coupled-cell linac (CCL) [1]. The model is the lowest-energy end of the DTL, being connected to a RFQ for a beam test; it accelerates protons from 3 to 5.4 MeV. The DTL has 18 cells and 8 post couplers; it is 1167 mm in length and 441 mm in diameter, and comprises two short unit tanks (about 0.6 m in length). The construction of the model was achieved by using many new techniques developed for the model in order to improve the fabrication accuracy of the DTL [2,3]. The results of the construction are described in reference [4]. The construction accuracy has already been confirmed mechanically. The performance of the high-power model of the DTL must be finally evaluated based on the RF characteristics.

The purpose of RF measurements is to confirm the following items:

1. Accuracy of the alignment and assembling of the unit tanks and drift tubes.
2. Uniformity and stability of the accelerating field.
3. Good RF contact of the tank and the surface condition of the tank wall.
4. Stability of the input coupler.

Items 1 to 3 are examined by a low-power RF test. A high-power RF test is used to examine mainly items 3 and 4.

The uniformity of the accelerating field significantly depends on the alignment accuracy of the drift tubes. We can thus confirm the assembling accuracy of the drift tube by measuring the field distribution. The DTL has 8 post couplers in order to stabilize the accelerating field against any perturbations which arise from structure imperfections, thermal detuning or beam loading. It is important for our purposes to tune the position of the post couplers.

Any discharge problem in the tank is related to the item 3. Furthermore, an RF input coupler (item 4) is one of the most important parts of a linac for stable operation. The input coupler of the DTL has a disk-type ceramic window in a coaxial line. It has been designed so as to feed 1MW peak RF power with a 3% duty into the DTL of the JHP.

Low-power test

We first measured the resonant frequency (f_0) and unloaded Q value (Q_0). Since Q_0 is affected by the surface condition of the copper and by any RF contact of the tanks, we can check the RF contact using the Q_0 value. In particular, since two short unit tanks and the end plates directly contact without any RF contactor, we can confirm the reliability of the direct RF contact by using the Q value. We also measured the field distribution on the beam axis by a bead-perturbation technique with an aluminum sphere (4 mm diameter). We calculated the transit time factor (TTF) and shunt impedance (Z) of the DTL using the field distributions. The position and rotation angle of the post couplers with the tab was also determined from the field distribution.

Figure 1 shows the dispersion curve without post couplers. We analyzed the confluent condition of the post-coupler

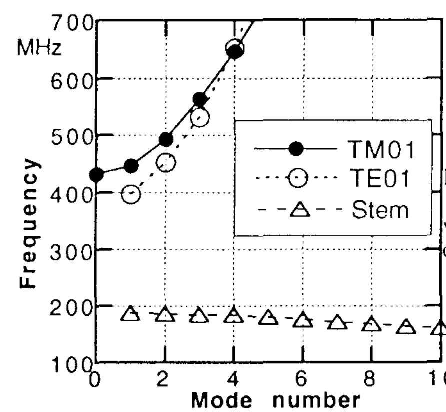

Fig.1 Dispersion curve without using post couplers.

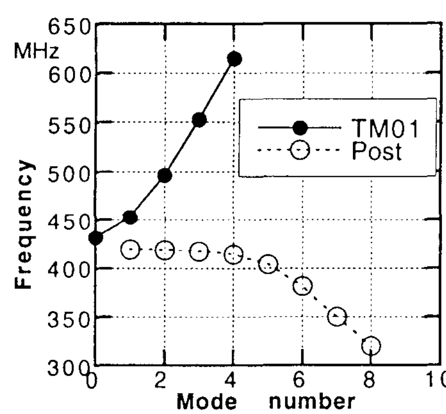

Fig.2 Dispersion curve with tuned 8 post couplers.

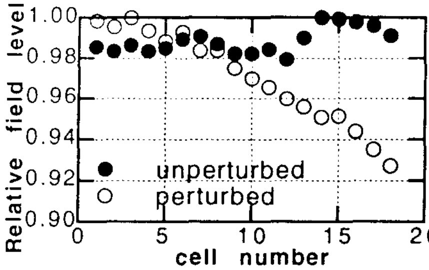

Fig .3 Average field distribution without using post couplers.

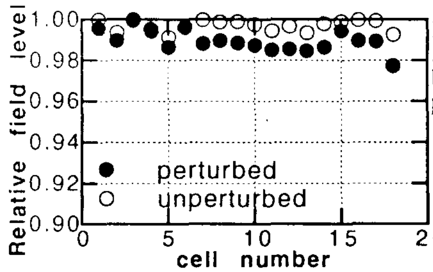

Fig .4 Average field distribution with tuned 8 post couplers.

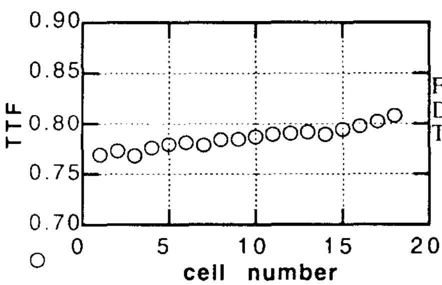

Fig .5 Distribution of the Transit Time Factor.

mode and the TM01 mode by changing the position of the post couplers, where a flatness of the field distribution is best against any perturbation. Figure 2 shows the confluent condition of the modes. The group velocity of the accelerating mode (TM010) is finite under the confluent condition, and is 0.13 c in our case, where c is the velocity of light. Figure 3 shows the distributions of the spatial average of the accelerating field in each cell. Post couplers have not yet been inserted in the DTL. The black and white circles in the figure indicate the distribution without and with a perturbation, respectively. A perturbation was made using a tuner located in the sixteenth cell. The standard deviation of the black circles is 0.6%. Figure 4 shows the field distributions after a position tuning of the post couplers, where a confluent condition of the mode was achieved. The black and white circles in the figure show the distributions with and without the perturbation, respectively. The distribution of the black circles indicates that the post couplers keep the field uniform against a perturbation. The standard deviations of the distribution of the black and white circles are 0.5 and 0.3%, respectively. The stabilized distribution with the post couplers is sufficiently uniform and stable.

The transit time factor (TTF) contains information concerning the field distribution in one gap. It is required for calculating the effective shunt impedance. It is designed to be near to 0.8. Figure 5 shows the transit time factors of the confluent condition of the modes.

The observed Q_0 value and Z are 43500 (near to 90% of the calculated value) and 82 MΩ/m, respectively. The Q_0 value is sufficiently high. A small reduction of the Q_0 from the calculated value mainly comes from imperfection of the DTL wall. The measured Z value suggests a peak power of 128 kW for the 3 MV/m accelerating field, which is the design value of the DTL. The maximum electric field on the drift tube in that case corresponds to 75% of Kilpatrick's limit.

High-power test

The RF power was fed into the DTL through a coaxial-line input coupler with a disk-type ceramic window. We modified the original design [5] in order to improve the impedance-matching property between the coaxial lines. Figure 6 (a) shows the modified design of the matching section around the ceramic window and the transformer between WX152D and WX77D coaxial waveguides. Figures 6 (b) and (c) show the design of the door-knob-type transformer between the WR1800 rectangular waveguide and the WX152D coaxial waveguide.

The DTL is evacuated by a 250 l/s ion pump and a 500 l/s turbo-molecular pump through slits on the bottom of the tank. The base pressures are 3×10^{-7} torr in the tank and 3×10^{-8} torr in the vacuum port of the ion pump, respectively.

The high-power test comprised two steps. The first was a conditioning of the ceramic window. RF power was fed from a driver amplifier of the 432 MHz klystron. The input power level was changed between about 1 and 100 watts. Figure 7 shows the RF field level in the DTL during the test. The input pulse was 50 watts and of 100 µsec duration at 10 Hz. The waved pattern of the signal shows a multipactor effect in the DTL. It started when the input power exceeded a few watts. At the second step, we used a klystron (Thomson TH-2134 [6]). The initial RF pulse was of 10 µsec duration at 10 Hz, and the peak-power level of the pulse was changed from a few 10 kW to 210 kW. By keeping the pressure in the vacuum port of the ion-pump less than 2×10^{-7} torr and monitoring the reflection power and tank field level, we gradually changed the pulse length and power level until the RF power entered the tank. After about a 10-minute trial, the RF power entered the DTL. Figure 8 shows the history of the conditioning up to 156 kW peak power at 3% duty. This is about 1.2-times the design value. The black circle in Fig. 8 shows the average power, which is the peak power multiplied by the duty factor. The white circles shows the peak power. The data are shown as a function of the conditioning time. The final result is shown in Fig. 9, where the input pulse is 156 kW peak, 600 µs duration at 50 Hz. Moreover, we successfully operated the DTL with an RF pulse which had a 230 kW peak power, and of 80 µsec duration at 10 Hz. The maximum electric field on the drift tube of that case was approximately the same as the value calculated by the Kilpatrick's sparking criterion.

Conclusion

We obtained adequate RF characteristics of a high-power model of 432-MHz DTL constructed for the Japanese Hadron Project because the DTL was accurately fabricated using new engineering techniques. The Q value of the DTL is close to 90 % of the calculated value. It shows the reliability of a method of direct RF contact without any RF contactor between the unit tanks and between the unit tank and an end plate of the DTL. The distribution of the accelerating field of the DTL was sufficiently uniform without using a post coupler because of the accurate alignment of the drift tubes. The accelerating field was stabilized by using post couplers against any perturbations. A high-power test of the DTL was carried out without any trouble up to about 1.2-times design value which is 156 kW peak power and of 600 µsec duration at 50 Hz. A coaxial input coupler with a disk-type ceramic window successfully fed the high-power RF into the DTL. Preparation for a beam-acceleration test is in progress.

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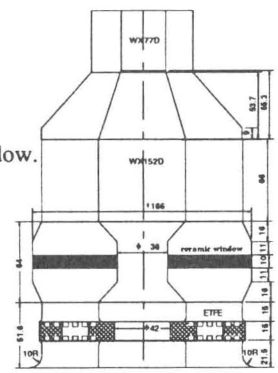
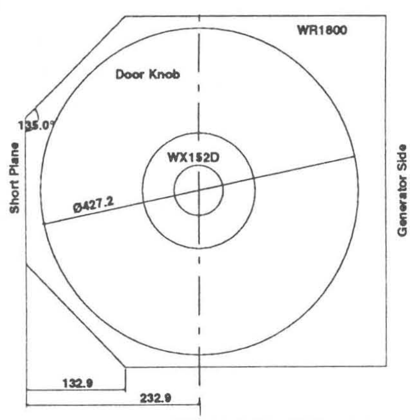
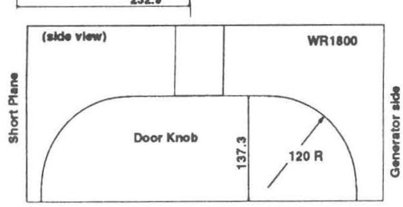


(a)



(b)



(c)

Fig .6
Design of the input coupler.
(a) Disk-type coaxial ceramic window.
(b) & (c) Door-knob transformer.

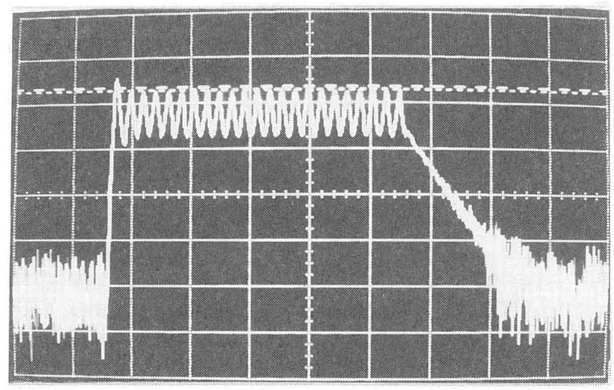


Fig .7 Photograph of the tank field level. It shows multipactoring in the DTL. The input pulse was 50 watts peak & 100 µs duration at 10Hz.

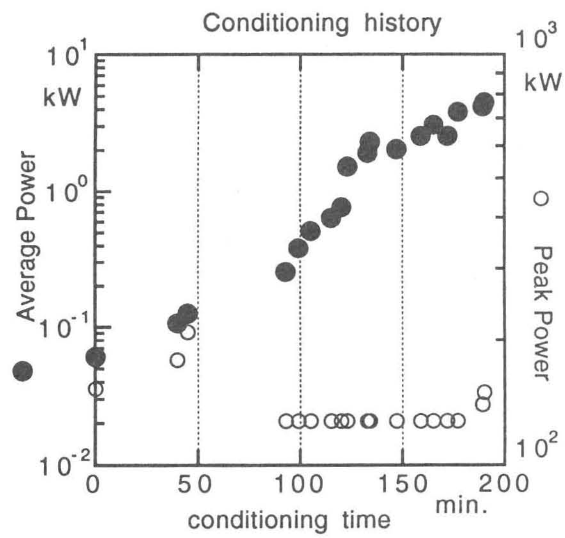


Fig .8 Conditioning history of the DTL. The black & white circles show average and peak RF power, respectively.

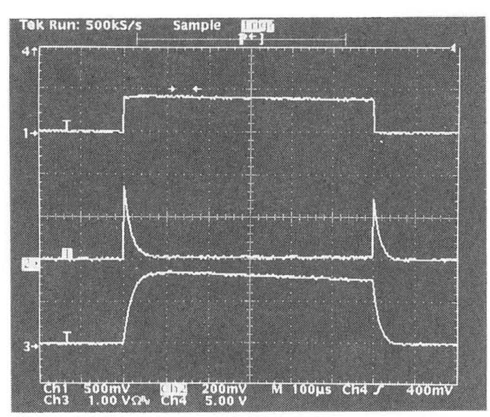


Fig .9 Observed signal of the DTL in a high-power test. The DTL input (top), reflected field level (middle) and tank field level are shown.