RF CHARACTERISTICS OF THE PEFP DTL*

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Abstract

A conventional 20 MeV Drift Tube Linac (DTL) for the Proton Engineering Frontier Project (PEFP) has been developed as a low energy section of a 100 MeV accelerator. The 20 MeV DTL consists of 4 tanks with 152 cells. The machine has a unique feature of driving 4 tanks with a single klystron. Therefore it has several control knobs to compensate the errors of each tank during operation. To develop the RF control scheme, the variations of the RF parameters of each tank were measured under various environmental conditions such as wall temperature, cooling water temperature, and cooling water pressure. In addition, the behaviours of the RF parameters among the tanks were also monitored during high power operation. In this paper, the measurement results are discussed and the control scheme based on the results is proposed.

INTRODUCTION

A 100 MeV proton accelerator is under development for the Proton Engineering Frontier Project [1-3]. For the first phase of the project, the construction of the 20 MeV accelerator which consists of the ion source, LEBT, RFQ and DTL has been completed. The overall system and the DTL tanks are shown in Figures 1.

The conventional type 20 MeV DTL is composed of 4 tanks and driven by a single RF source in contrast to the usual method of an RF feeding to the DTL tanks where there are as many RF sources as DTL tanks. To drive all of the four tanks with a single RF source, the RF power from the 1 MW klystron is split into 4 directions using magic T. The RF system has a phase shifter with three stub tuners in each waveguide leg which can only be adjusted manually. The phase shifter can be used for compensating for the initial phase difference between each tank. The schematic layout of the RF delivery system of 20 MeV DTL can be seen in Figure 2.

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RF CHARACTERISTICS MEASUREMENTS OF DTL

Unloaded Quality Factor

The unloaded quality factors of the DTL tanks were measured using network analyzer and the measurement results are summarized in Table 1. As can be seen in Table 1, the measured unloaded quality factors are more than 80% of the calculated values.

Table 1: Unloaded Q of the DTL tanks

	Calculated	Measured	Ratio
Tank1	47990	39500	82.3%
Tank2	50560	42200	83.0%
Tank3	52630	42500	80.8%
Tank4	53540	45900	85.7%

Coupling Coefficient of RF Power Coupler

The RF power couplers used in PEFP DTL are iris couplers with ridge-loaded waveguide as shown in Figure 3. The coupling coefficient of the RF power coupler is

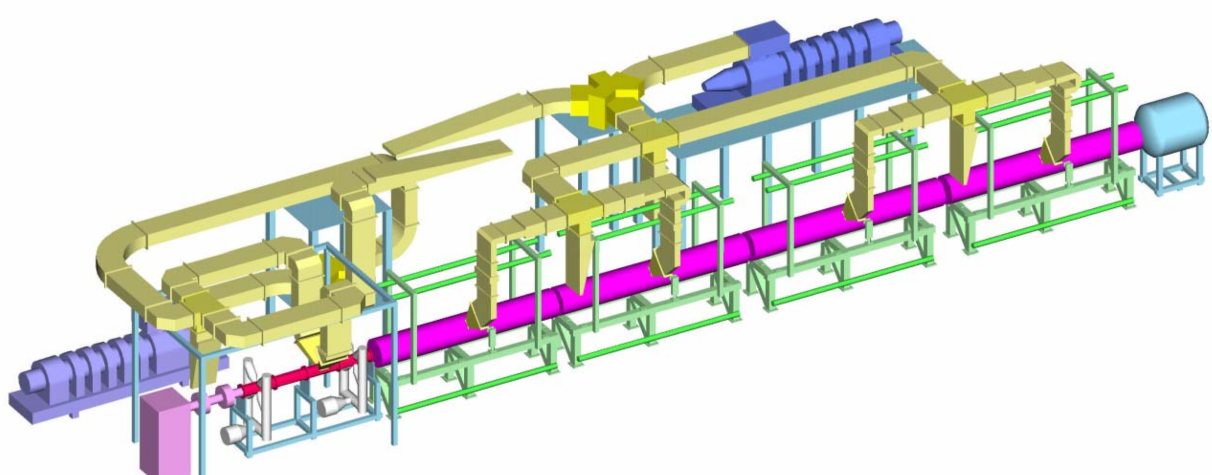

Figure 1: Overall system of the PEFP 20 MeV accelerator

adjusted by enlarging the coupling hole size step by step. The optimum coupling coefficient of the DTL tanks is about 1.6 with beam loading of 20 mA to minimize the required RF generator power. The dependency of the coupling coefficient on the coupling hole size has been studied analytically and compared with the numerical results and the measurements as shown in Figure 4 [4]. The coupling coefficient was shown to be proportional to the third power of the coupling hole radius. The optimum coupling coefficient was obtained with the coupling hole radius of about 7.5 mm. The coupling coefficient adjustment results are summarized in Table 2.

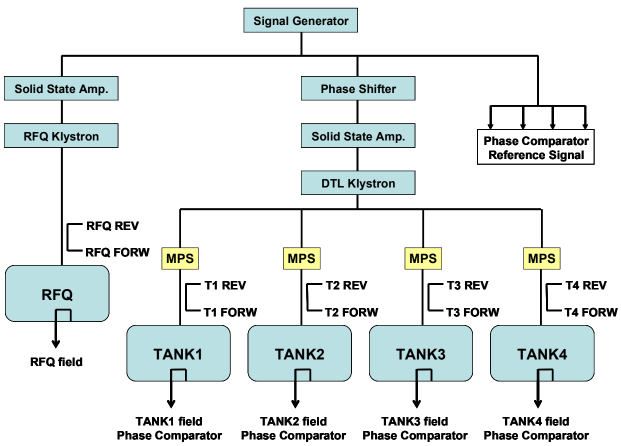

Figure 2: Schematic layout of the RF power flow

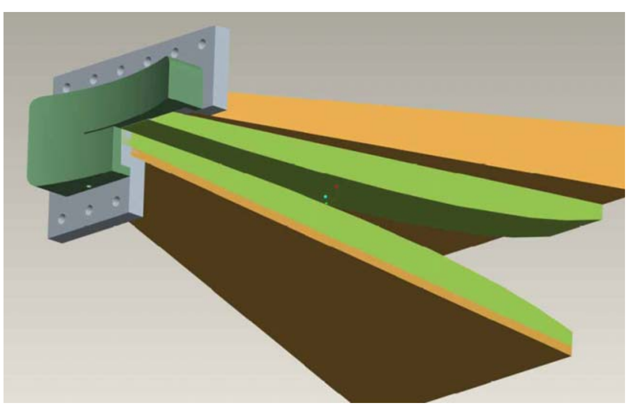
Figure 3: RF power coupler with ridge-loaded waveguide

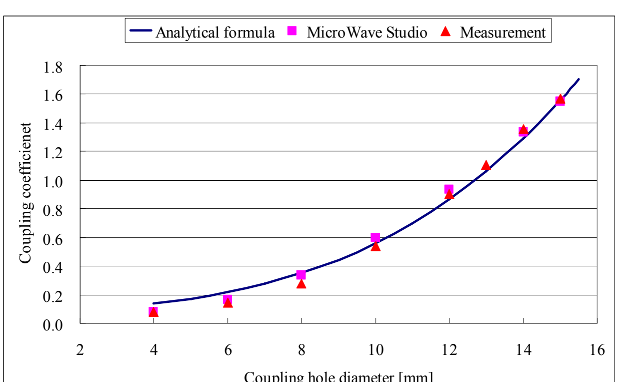

Figure 4: Coupling coefficient as a function of coupling hole size variation (DTL tank4 case)

Table 2: Coupling coefficient of DTL tanks

	Optimum value with 20 mA beam loading	With 7.5 mm coupling hole radius
Tank1	1.59	1.4138
Tank2	1.62	1.5499
Tank3	1.62	1.3295
Tank4	1.61	1.5623

Resonant Frequency Characteristics

The resonant frequency of the DTL tank is changed by evacuation. The resonant frequency shift due to the evacuation can be calculated by using the permittivity of air as a function of the temperature and relative humidity. The estimated resonant frequency shift of the PEFP DTL tank was about 104 kHz. The measured resonant frequency shifts before and after the evacuation are summarized in Table 3. During the measurement, the tank wall temperature was kept at constant value of 37 ℃.

Table 3: Resonant frequency shift due to the evacuation

	Before evacuation	After evacuation	Frequency shift
Tank1	349.923 MHz	350.015 MHz	93 kHz
Tank2	349.916 MHz	350.014 MHz	98 kHz
Tank3	349.910 MHz	350.016 MHz	106 kHz
Tank4	349.921 MHz	350.018 MHz	98 kHz

The resonant frequency of the DTL is very sensitive to the temperature of the DTL tank wall and drift tube. The frequency sensitivity on the temperature was estimated by using the ANSYS and SUPERFISH code and summarized in Table 4.

Table 4: Frequency shift due to temperature change

cell		Condition 1 [kHz/℃]	Condition 2 [kHz/℃]
Tank1	Low energy end	-5.47	-4.49
	High energy end	-5.29	-3.95
Tank2	Low energy end	-5.29	-3.95
	High energy end	-5.20	-3.69
Tank3	Low energy end	-5.20	-3.68
	High energy end	-5.15	-3.52
Tank4	Low energy end	-5.14	-3.51
	High energy end	-5.11	-3.40

Condition 1: wall & DT temperature change
Condition 2: only DT temperature change

HIGH POWER RF DRIVING TEST

The high power RF test was carried out. The vacuum levels of each DTL tank were better than 8E-7 torr and those of each RF window region were better than 6E-8 torr. During the initial RF test, the RF pulses with 50 μs duration and 2 Hz repletion rate were applied. At such low power level as several kW, the reflected power level was high and the waveform was unstable. However, the

RF pulse profiles were stabilized above about 50 kW forward power level. From this power level, the RF power was increased up to 150 kW for each DTL tank without any electron loading effect or sparks. The RF pulse length also increased up to 100 µs. The waveforms of the cavity field and reflected RF power are shown in Figure 5 and 6, respectively.

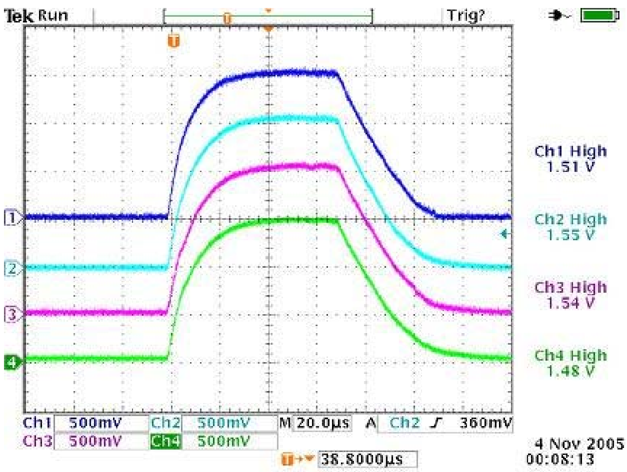

Figure 5: Cavity field waveform
(CH1: tank1, CH2:tank2, CH3:tank3, CH4:tank4)

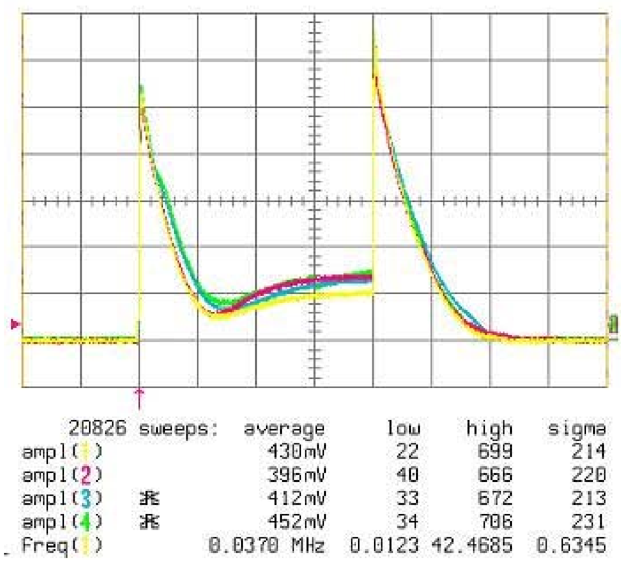

Figure 6: Reflected power waveform
(CH1: tank1, CH2:tank2, CH3:tank3, CH4:tank4)

The RF phase of the DTL tank was measured by using the RF phase comparator. Four phase comparators are used to measure the phase between the reference signal from the RF signal generator and the RF pickup signal from each tank. The phase comparator is four-port device with LO port for reference input, RF port for RF signal input and two output ports. Outputs of the phase comparator are $\sin\varphi$ and $\cos\varphi$, where φ is the phase difference between the reference signal and RF signal. The measured tank phase should be compensated considering the phase delay of each signal line. Without phase shifter adjustment, the relative phase error between each tank is amount to about ±16˚. After rough adjustment by using the mechanical phase shifters, the relative phase error reduced to about ±6˚. During the high power RF test including the tank phase measurement, there was no feedback or feedforward control in the low level RF system, that is to say, the RF system was operated in open-loop control. To further reduce the relative phase error, several methods such as the fine adjustments of the phase shifter and feedback control in the LLRF are being considered.

RESONANCE CONTROL SCHEME

As stated earlier, the single RF source for a multi-cavity scheme adopted for the PEFP DTL makes it difficult to use the LLRF system for a resonance control of each tank because the changes made in the LLRF affect all of the four tanks simultaneously. Therefore we need some other methods to control the resonance of each tank independently. For this purpose, we are going to use the thermal expansion of a drift tube as an active frequency tuner. All of the drift tubes have a quadrupole electromagnet, so the thermal expansion of the drift tube can be controlled by adjusting the temperature of the coolant. The detailed study on this subject is ongoing.

CONCLUSION

The construction of the PEFP 20 MeV DTL has been completed and the RF parameters of the fabricated DTL such as quality factor, coupling coefficient of the RF power coupler and resonant frequency characteristics are surveyed, which shows the measured values are reasonably matched with the expectations. The high power RF tests were carried out and the design power level was achieved at low repetition rate. The RF phase of the DTL tanks was measured and the relative phase differences among tanks were shown to be reduced by using the mechanical phase shifter. Up to now, all of the RF operations were performed with open-loop mode. The LLRF system for the feedback control is under development. If the machine is equipped with LLRF, the RF phase characteristics are expected to be greatly improved.

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