CONTROL CHARACTERISTICS OF THE PEFP RF SYSTEM*

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Abstract

A 20 MeV proton accelerator has been developed and tested at Proton Engineering Frontier Project (PEFP) as a front-end part of the 100 MeV accelerator. The initial test results showed that more stable RF operation was necessary to investigate the machine characteristics more comprehensively. A LLRF control system using commercially available digital board was newly developed and tested for this purpose. The goals of the RF control for 20 MeV accelerator are to achieve errors within 1% in amplitude and 1 degree in phase against external perturbations such as change of resonant frequency, fluctuation of klystron power supply voltage and also beam loading. In addition, the PEFP 20 MeV DTL has unique characteristics that single klystron drives four independent tanks simultaneously. In this paper, the initial test results of the RF system with digital controller are presented and its control characteristics are discussed.

INTRODUCTION

One of the missions of PEFP is to develop a 100 MeV proton linear accelerator. For this purpose, a 20 MeV accelerator was already fabricated and installed at KAERI test stand [1][2]. About two years later, the 20 MeV accelerator will be moved to be installed in Gyeongju city which was selected as an host city for PEFP 100 MeV accelerator. An initial test has been carried out at KAERI site to check the overall machine performance and tune the accelerator operating parameters. The test is being done with peak current of 1 mA at low duty, that is 50 µs beam pulse width and 0.1 Hz repetition rates, because of the improper radiation shielding for full beam power. The installed 20 MeV accelerator at KAERI site is shown in Figure 1. During the initial beam test, nearly 100 % beam acceleration was achieved through the four DTL tanks. But the pulse to pulse beam current fluctuation was observed. Moreover the beam current dependency on the tuning parameters such as RF power, RF phase, beam steering were not so obvious in the near 100 % beam transmission level. Therefore, more stable RF control system was necessary to investigate the machine performance more comprehensively. A digital control LLRF system was developed to satisfy the requirement [3]. Recently, the high power test using newly developed LLRF control system is being carried out to check the RF system characteristics and optimize the control parameters. In addition, the PEFP 20 MeV accelerator has unique characteristics, that is four independent tanks are driven by single klystron. Several methods were adopted to realize this scheme, and the DTL tank characteristics were investigated to obtain the basic parameters for the proper RF control.

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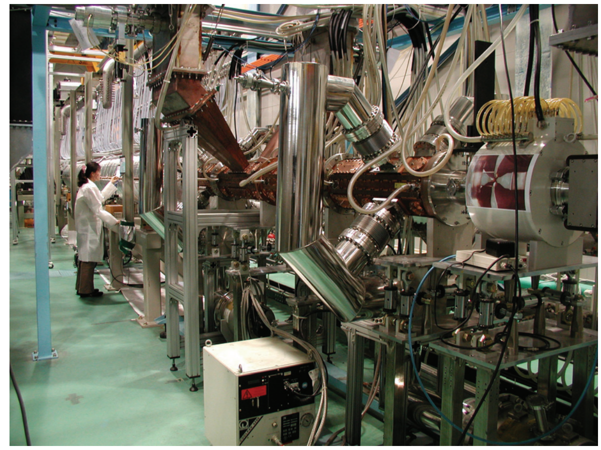

Figure 1: 20 MeV proton accelerator installed at KAERI test stand.

20 MEV ACCELERATOR TEST STAND

The main accelerator facilities at KAERI test stand are 20 MeV accelerator itself, two sets of 1 MW, 350 MHz RF system, two sets of –100 kV, 20 A DC high voltage power supply for the klystron, two sets of 2 MW cooling system for the cavity and RF system.

The ambient condition at KAERI test stand is not stabilized. Therefore the RF cavities should be stabilized against changing ambient conditions – especially ambient temperature. For this purpose, heater and heat shield were installed around the RFQ and DTL cavities. A 1 kW heating power per RFQ and a DTL tank was used. The heater was controlled by PID mechanism of the SCR power unit. By using this method, the frequency could be stabilized within ± 1 kHz.

The design duty of the 20 MeV accelerator is 24 % and two sets of 1 MW, 350 MHz klystron are used to drive a 20 MeV accelerator, one is for RFQ and the other is for DTL. All the other ancillary facilities such as klystron power supply and cooling system were designed for 100 % duty operation. During the low duty operation at KAERI test stand, the RF system is operating such that the electron beam of the klystron is CW whereas only the input RF signal is modulated for the low duty pulse operation.

Two sets of klystron power supply are used to drive two sets of 1 MW klystron. As mentioned above, the design duty of 20 MeV accelerator is 24 %, therefore, not modulator, but DC high voltage power supply is used as a klystron power supply. During test, the klystron power supply is operating in CW mode.

Two sets of cooling system are operating, one is for RFQ, the other is for DTL. One set of the cooling system at KAERI test stand supplies cooling water both to the klystron and cavity simultaneously. With this cooling circuit configuration, the thermal load can be maintained nearly constant irrespective of the duty factor. Three-way valve is used to control the cooling water temperature during operation.

RF CONTROL CONCEPT OF THE 20 MEV DTL

The resonant frequencies of each DTL tank should be controlled independently. There are no frequency tuners in PEFP DTL. It is planned to adjust the resonant condition of each tank with cooling water temperature. Therefore the RF control concept is such that the RF system controls the RF amplitude and phase of the DTL tank with the signal from the reference tank (for example tank1), and the resonance control cooling system adjusts the frequency of each tank with the phase error signals between controlled tank and the reference tank. The cooling water unit for the resonance control (namely RCCS – Resonance Control Cooling System) will be installed for the control of each tank at Gyeongju site. Instead, the heater installed at each tank was used to adjust the resonant condition at KAERI site. One of the reasons to use the heater as a controller is that there is no test schedule requiring appreciable RF heat load at KAERI site.

The cooling water system is configured such that the klystron and four DTL tanks are connected in parallel at KAERI site. With this configuration, the main heat source is the klystron. The heat load from the DTL is only due to the quadrupole magnet cooling. A three-way valve was installed in the cooling loop to control the water temperature. During the test, the total heat loads was 1,330 kW, that was 1,200 kW from the klystron and 130 kW from the quadrupole magnet. With these conditions, the three-way valve could maintain the coolant temperature within ± 0.2 °C with standard deviation less than 0.1 °C.

HIGH POWER RF TEST OF DTL TANKS USING DIGITAL LLRF SYSTEM

After the low level test using dummy cavity [3], the high power RF test was done using newly developed digital LLRF system. As stated earlier, four independent DTL tanks were driven by single klystron. The power from the klystron is divided into four legs using magic tee. The mechanical phase shifter was installed to each waveguide leg to adjust the initial phase difference between waveguide legs. During initial test, the pickup signal from tank2 was used as a control signal instead of the vector sum signal of all four tanks. The pulse length was 200 μs and repetition rate 0.1 Hz during test. After adjusting the resonant conditions of each using heater, the high power RF test was carried out.

The loop gain and signal delay of the whole high power RF system were measured. The loop gain was about 0.76. The delay times with the reference to the system trigger were ~ 4 μs to the solid-state amplifier output, ~ 4.5 μs to the klystron output, and ~ 5.0 μs to the control board. The intrinsic delay due to the digital filter of the digital control board was ~ 2.5 μs, which was included in the ~ 4 μs delay to the solid-state amplifier output.

The forward power from the klystron and the tank power are shown in Figure 2. The P / I (Proportional / Integrate) gain values were 1.0 and 70,000 respectively. The set table was step function shape, and anti-windup scheme was used. As shown in the Figure, the klystron output power is overshooting as a response to the step function command. The typical reflected power from the tanks is shown in Figure 3. The tank is slightly over-coupled considering the beam loading effect.

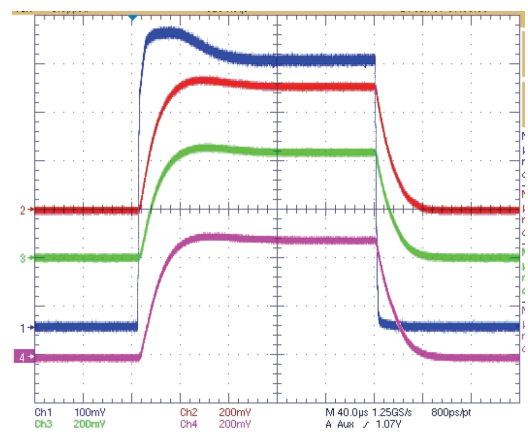

Figure 2: RF power profile (ch1 : klystron output power, ch2: tank1, ch3 : tank2, ch4 : tank3, horizontal : 40 μs/div.).

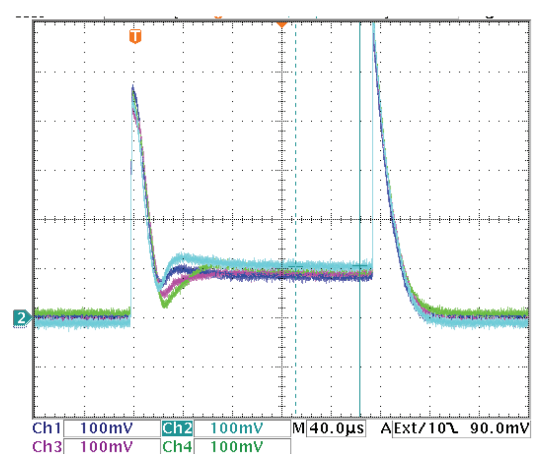

Figure 3: Reflected RF power profile (ch1 : tank1, ch2: tank2, ch3 : tank3, ch4 : tank4, horizontal : 40 μs/div.).

The phase and amplitude of the tank RF power were measured during test. The measured RF amplitude was scattered within 0.1 % of the set value and the standard deviation was about 0.02 %. The measured RF phase was scattered within 0.15 degree from the set value with standard deviation of 0.03 degree. The measured data during 1 hour are shown in Figure 4 and Figure 5 respectively. The relative phase variations of each tank referenced to tank2 were also measured during test and the result is shown in Figure 6. The wall temperature of the tank1 is not stabilized during measurement, therefore the phase is monotonically increasing. As shown in the Figure, the phase of tank3 also showed some fluctuation, which results from the ± 0.1 °C temperature variation of the tank wall. Except tank1, the relative phase variations of all the other tanks with respect to the tank2 are within ± 0.5 degree with standard deviation less than 0.2 degree.

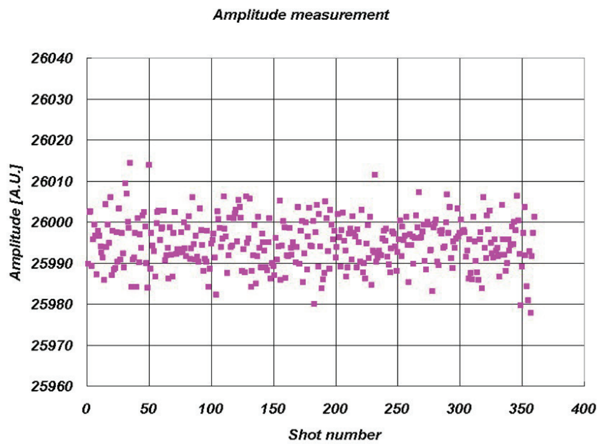

Figure 4: RF Amplitude fluctuation during feedback control (DTL tank2).

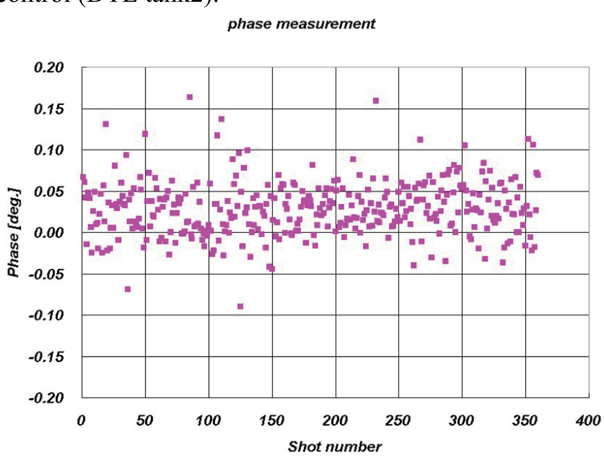

Figure 5: RF phase fluctuation during feedback control (DTL tank2).

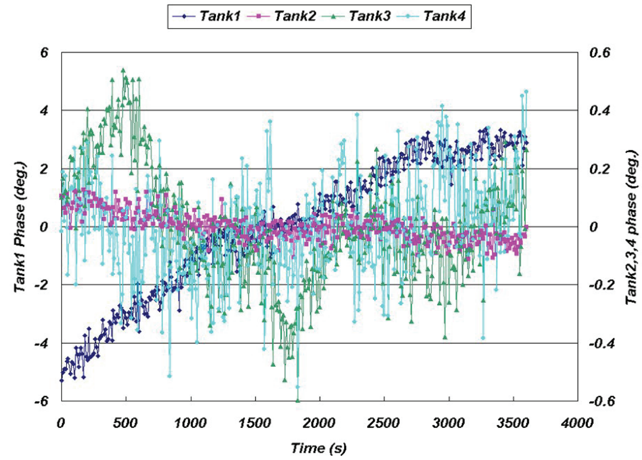

Figure 6: Relative Tank Phase Variation With Respect To Tank2 During High Power Rf Test.

CONCLUSION

The initial high power test of the PEFP DTL using newly developed LLRF system was carried out. To accomplish the proper RF control of four tanks driven by one klystron, heater at tank wall was used to control the resonance frequency of each tank and the global resonant condition was adjusted by the cooling water temperature. With this concept, the four independent tanks can be considered as a single tank. For the RF control test, system parameters such as loop gain and signal delays were measured. The three-way control valve could effectively stabilize the cooling water temperature. With this condition, the RF amplitude and phase could be maintained within required values. The relative phase variations also measured and tank1 needs re-adjustment of the control parameter of the wall temperature.

The control gain values need to be optimized from several criteria. In addition, the control system algorithm needs to include the feed-forward to compensate the beam loading effect. Before that, we should carefully check the stabilization of the tank parameters to distinguish the real RF control effect from the environmental noise and determine the control capability.

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