KLYSTRON AND MODULATOR SYSTEM FOR THE PEFP 20 MeV PROTON LINAC*

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Abstract

A modulator developed for the 100MeV proton linear accelerator is operating in the 20MeV proton linac. The voltage and current of the modulator are -105kV, 50A with 1.5ms pulse width, 60Hz repetition rate. The modulator drives two klystrons simultaneously, one for the RFQ, the other for the DTL. The typical operation parameters of the modulator are 85kV of the peak voltage, 34A of the peak current, 1 ms of the pulse width, 4Hz of the pulse repetition. The specifications of the klystron are 350MHz of the frequency, 1.1MW of the maximum average RF power, less than 95kV of the beam voltage, triode type electron gun with mod-anode. The mod-anode voltage was supplied by the voltage dividing resistors which were located inside the klystron oil tank. In this paper, the operation performance of the klystron and modulator system for the PEFP 20MeV proton linac is presented.

INTRODUCTION

The modulator for the 100MeV accelerator was installed to drive the 20MeV linac. The purpose of the test was to test the modulator in the real system in advance before it would be installed for the 100MeV accelerator at Gyeong-Ju site [1].

The modulator was operated at KAERI site from 2009. It is based on the high frequency switching method with Insulated Gate Bipolar Transistor (IGBT) and the topology of the modulator was originally developed for the SNS modulator. A modulator was used to drive two klystrons simultaneously. These klystrons were triode type with mod-anode. The mod-anode voltage for the klystron was supplied by dividing the high voltage by using voltage dividing resistors [2].

The voltage dividing resisters were tested and installed inside klystron oil tank for the RFQ klystron [3]. The measured values of the klystron at the factory were such that 0.68 uperv. in beam perveance, 1.44 uperv. in gun perveance. To check the operation characteristics of modulator and klystron system, the klystron perveance and RF gain were measured.

KLYSTRON FOR 20MEV LINAC

The klystron (TH2089F, THALES) for 20MeV linac has a triode type electron gun. Therefore, modulating anode voltage should be supplied. The specifications of the klystron are shown in Table 1. The klystron for RFQ is shown in Figure 1.

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Table 1: Specifications of the Klystron

Parameter	Value
Operation frequency	350MHz
Average RF power	>1.1MW
Beam voltage	<-95kV
Beam current	<20A
Electron gun type	Triode
Arc energy	<20J

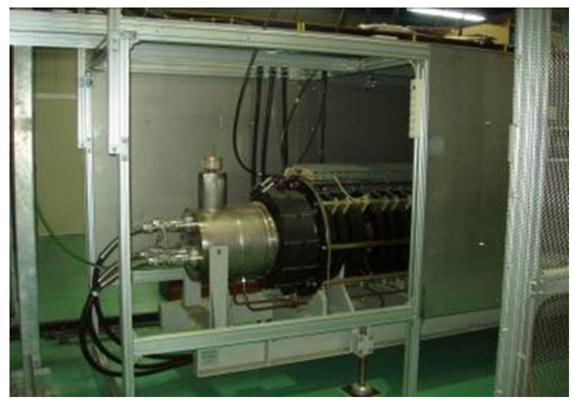

Figure 1: Klystron for the RFQ.

Recently the klystron has gone through some modification including the modulating anode voltage supply circuit. Formerly, the mod-anode voltage was supplied by using the tetrode-controlled voltage divider. This type of voltage divider has some merits such that the mode-anode voltage can be controlled without changing the cathode voltage. However, it requires addition power supply for the tetrode and the grid control circuit. On top of that, it occupies large space for installation and electrical isolation. Therefore, we modified the mod-anode supply from tetrode-controlled voltage divider to a resistive voltage divider. With a resistive voltage divider, the system can be made simple and occupies virtually no space because it can be installed inside the klystron oil tank as shown in Figure 2.

The voltage dividing resistors which were installed in the klystron oil tank were connected in parallel with the klystron load to produce the modulating anode voltage by using the applied cathode voltage. The power rating of the resistor (SR60HVP, E&C) was confirmed that it could be increased by 5 times when the resistor was in the oil compared with in the air. The voltage dividing ratio was determined to be 6:4 for adjusting the beam perveance of about 0.7 uperv.

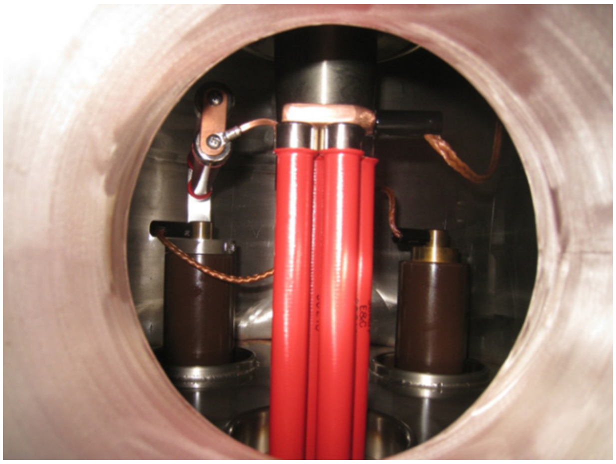

Figure 2: Installed voltage dividing resistors inside the klystron oil tank of RFQ.

MODULATOR FOR KLYSTRON

The modulator for the klystrons consists of a control rack, SCR unit, high voltage converter modulator which includes oil tank basket, capacitor bank, IGBT switching plates, and tank assembly. The specifications of the modulator are shown in the Table 2.

Table 2: Specifications of the Modulator

Parameter	Value
Input voltage	3300Vac
Input frequency	60Hz
Output DC voltage	-105kV, +10%, -50%
Output current	50A
Output peak power	5.8MW
Output average power	520kW @ 9% duty
Efficiency	>92%
HVCM waveform	Square wave
Pulse width	1.5ms
Max. repetition	60Hz
Flat top regulation	1%
Flat top voltage droop	1%
Pulse rise time	<0.1ms
Pulse fall time	<0.1ms
Flat top minimum	<0.1ms
Arc energy	<20J

A modulator was used to drive two klystrons for the 20MeV linac simultaneously. The typical operation parameters of the modulator during the operation of the 20MeV proton linac were 85 kV of the peak voltage, 34A of the peak current, 2.4MW peak power with 1ms pulse width and 4Hz repetition rate. The voltage droop was 1.8% which increased to 3% at full peak power. We are going to reduce the droop within 1% by controlling the IGBT switching pulse width or frequency. The modulator installed to drive the klystrons is shown in Figure 3.

Figure 3: Installed modulator at KAERI.

The pulse profile of the modulator during the operation is shown in Figure 4. The output voltage and total current were measured by using the modulator controller signal. In addition, the current profiles of each klystron were measured by using Rogowski coil (PEM, CWT3LFB).

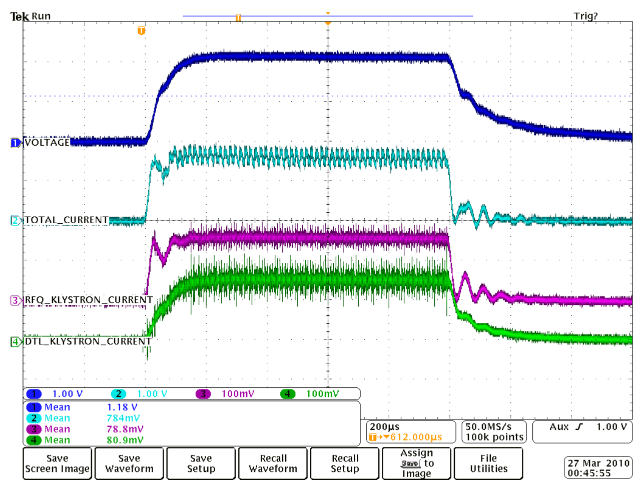

Figure 4: Voltage and current profile of the modulator. (Ch 1: Voltage (40kV/V), Ch 2: Total current (20A/V), Ch 3: RFQ klystron current (1A/10mV), Ch 4: DTL klystron current (1A/10mV), Horizontal scale: 200us/div.)

The voltage droop and flat top average voltage were 1.8% for the 1ms and 86.8kV, respectively. The voltage droop will be within 1% by adopting the droop compensation method using pulse frequency modulation algorithm. The rising time was less than 200us, which was about 70us at Factory Acceptance Test (FAT). Also the current waveforms of the two klystrons were different from each other. The reason for the long rising time and differences in the current waveforms was mainly due to the stray components of the high voltage transmission line between the modulator and klystron. The output voltage showed long-term decrease of about 0.8% from the initial value. One of the reasons for the voltage decrease is attributed that the modulator average power during test was much lower than the design value that is 520kW. The voltage fluctuation around the average was less than 0.2%.

TEST OF KLYSTRON AND MODULATOR

The RF output power was measured to check the effect of the voltage dividing resistors. The low level RF (LLRF) system was operated during the measurement to maintain the constant RF amplitude and phase.

Figure 5 shows the RF waveforms of the RFQ, which includes the forward power from the solid state amplifier, the forward power from the klystron, the reverse power from the RFQ and RFQ pickup signal. The pulse width and the forward power were 500us and 420kW, respectably.

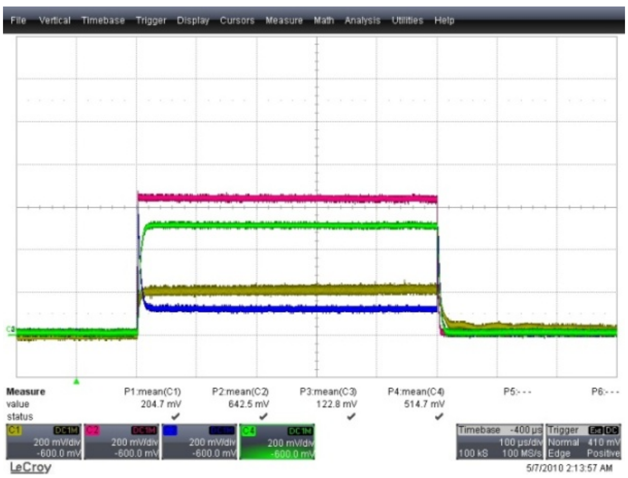

Figure 5: RF pulse shape of the RFQ.

The klystron operation with this dividing ratio resulted in the beam perveance of 0.74 uperv. and RF gain of 49.4 dB, respectably, which were slightly different from the FAT values. The repetition rate of the modulator was increased up to 20Hz without any difficulty as shown in the Figure 6.

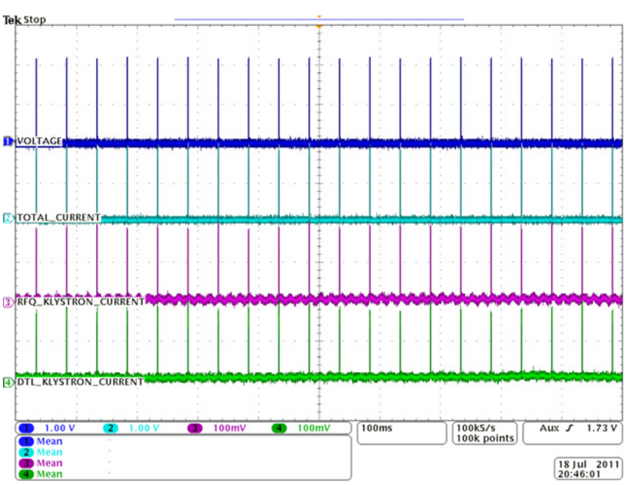

Figure 6: 20Hz of the modulator operation (horizontal: 100ms/div).

CONCLUSION

A modulator was used to drive two klystrons for the 20MeV linac at KAERI since 2009. The operation characteristics of the klystron and modulator system were measured and checked. The modulator was operated up to 20Hz of repetition rate. The voltage dividing resistors for mod-anode supply were installed in the klystron oil tank. During the 20MeV linac operation, the klystron perveance and RF gain were measured and showed slight differences from the FAT values. The klystron perveance and RF gain require further optimization for better performance and the dividing ratio of voltage divider should be adjusted and checked.

REFERENCES

[1] Hyeok-Jung Kwon, et al., “Operation of the PEFP 20MeV Proton Linac at KAERI” IPAC10, Kyoto, 2010.

[2] Hyeok-Jung Kwon, et al., “Test of the 20-MeV Proton Accelerator Using Modulator” Transactions of the Korean Nuclear Society Spring Meeting, Pyeongchang, Korea, May 27-28, 2010.

[3] Dae-Il Kim, et al., “Power rating measurement of the voltage divider resistors for the klystron modulating anode” Transactions of the Korean Nuclear Society Spring Meeting, Pyeongchang, Korea, May 27-28, 2010.