Test of the 20-MeV Proton Accelerator Using Modulator

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1. Introduction

A 20-MeV proton accelerator has been installed and operated at Korea Atomic Energy Research Institute (KAERI) site by Proton Engineering Frontier Project (PEFP), which consists of a 50-keV proton injector, 3-MeV Radio Frequency Quadrupole (RFQ), 20-MeV Drift Tube Linac (DTL), two sets of klystrons including power supply systems and cooling systems [1]. A modulator developed for the 100-MeV DTL was installed and tested at KAERI site in 2009 using two klystrons as high power loads. After the modulator test, overall 20-MeV machine test including beam acceleration was carried out to check not only the operational characteristic of the modulator itself but RF and beam characteristics. In this paper, the test results are presented.

2. Modulator and Klystron System

The RF system of the 20-MeV proton accelerator is such that two klystrons are used to drive the machine, one for the RFQ, the other for the DTL, and one modulator is used to drive two klystrons at once. Two sets of cooling system are also installed, one for the RFQ high power system, the other for the DTL high power system.

2.1 Modulator

A high voltage converter modulator type pulse power supply has been developed for the 100-MeV DTL. The specifications of the modulator are as follows.

- Input voltage: 3300Vac
- Input frequency: 60Hz
- Output DC voltage: -105kV, +10%, -50%
- Output current: 50ADC
- Output peak power: 5.8MW
- Output average power: 520kW at 9% duty
- Efficiency: > 92%
- HVCM waveform: square wave
- Pulse width: 1.5ms
- Max. repetition rate: 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

The characteristics of the modulator is that it uses a high frequency switching method and can produce effective output voltage ripple frequency of 120kHz, which is capable of using small capacitors with low stored energy. The modulator was delivered to the KAERI site in 2009 and installed to perform the initial test. After the initial test with 2kW dummy load which consists of the non inductive high power resistors, the modulator was connected to the two klystrons to do the test at higher power level [2]. The modulator installed to drive the klystron is shown in Fig. 1.

Fig. 1: Modulator installed at KAERI site

2.2 Klystron

The specifications of the klystron (TH2089F, THALES) are as follows.

- Frequency: 350MHz
- Max. average RF power: > 1,100kW
- Beam voltage: < 95kV
- Cathode current: 19A @ max. RF power
- Gun perveance: 1.4~1.6 uperv.
- Gain: > 40dB
- Efficiency: > 60%
- Electron gun type: Triode

Voltage dividing resistors were installed in parallel to the klystron load to produce the modulating anode voltage using the applied cathode voltage. Capacitors were also installed in parallel to the voltage dividing resistors to reduce the rising time of the voltage pulse applied to the modulating anode. The resistors and capacitors used for each klystron are summarized in Table 1.

Table I: Resistors and Capacitors

	RFQ klystron	DTL klystron
Beam perv.	0.66 uperv.	0.68uperv.
Resistor[Mohm]	3.12 / 2.27	3.12 / 2.29
Capacitor [nF]	3.29 / 0.43	3.29 / 3.44

2.3 Modulator and Klystron Tests

The modulator and klystron systems were tested up to 87kV, 32A which correspond to the 2.8MW peak power with 1ms pulse length and 4Hz repetition rate. The pulse profile is shown in Fig. 2. The voltage and total current was measured by using the controller signal, the current of each klystron was measured by using Rogowski coil (PEM, CWT3LFB). The voltage droop was 1.8% for the 1ms pulse.

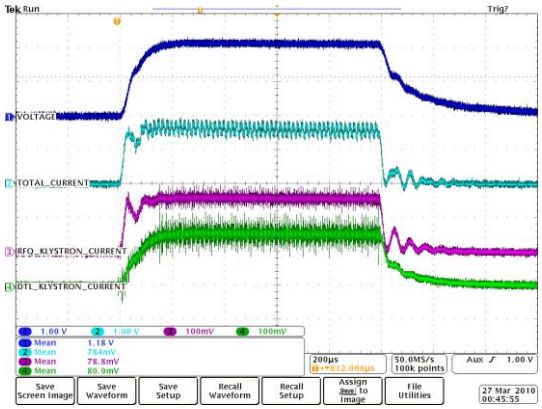

Fig. 2: Voltage and current profile of the modulator.
(Ch 1: Voltage (40kV/V), Ch 2: Total current (20A/V),
Ch 3: RFQ klystron current (1A/10mV), Ch 4: DTL klystron current (1A/10mV), Horizontal scale: 200us/div.)

3. 20-MeV Accelerator Test

The modulator and klystron systems were driven to operate the 20-MeV accelerator. The average number of pulse of the modulator during the test was about 130,000. The example of the modulator voltage during test was shown in Fig. 3. In this case, the operation time was 8 hours with 4Hz repetition rate. The voltage decreases about 0.7% for 8 hours and the standard deviation of the voltage was 0.2%. The reason of the voltage decrease should be checked.

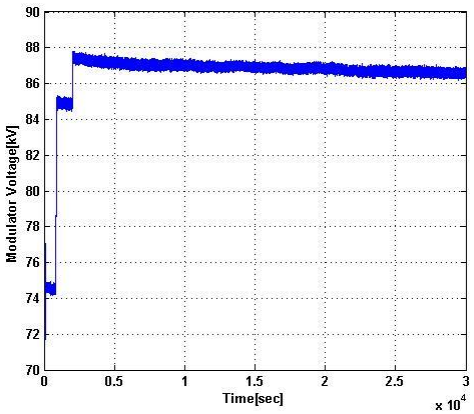

Fig. 3: Modulator voltage for 8 hour operation

The RF pulse profile of the RFQ driven by modulator was shown in Fig. 4. The peak RF power was 440kW with 100us pulse with and 2Hz repetition rate. The forward power showed ripple like waveform which should be carefully checked whether it was a real signal caused by the modulator or not. The low current beam acceleration test was also carried out. We could not observe any noticeable problems of the 20-MeV accelerator system driven by modulator.

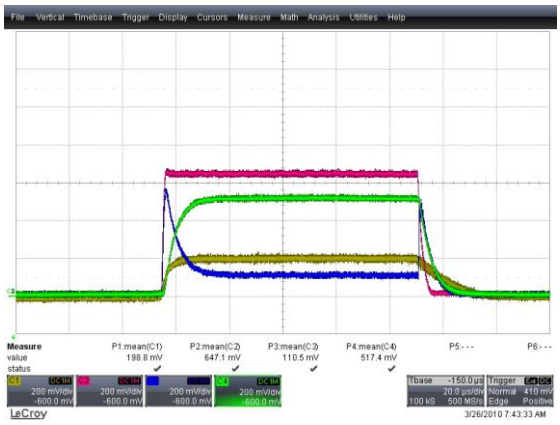

Fig. 4: RF signal of the RFQ.
(Ch 1: SSA forward, Ch 2: Klystron forward,
Ch 3: Reverse from cavity, Ch 4: Cavity,
Horizontal scale: 20us/div.)

4. Conclusions

The 20-MeV proton accelerator was tested with the modulator. The routine operation time of the modulator was 8 hours without trip, which correspond to the 4 hours beam test time per week. The RF test and beam test were carried out without any noticeable problems using modulator.

Acknowledgement

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REFERENCES

[1] Yong-Sub Cho, et al., Beam Test Results of the PEFP 20-MeV Proton Accelerator at KAERI, Proceedings of the LINAC Conference, Oak Ridge, 2008.
[2] Daeil Kim, et al., Arc Energy Limiting Mechanism of the High Voltage Converter Modulator, Transactions of the Korean Nuclear Society Autumn Meeting, Gyeongju, Korea, October 29-30, 2009.