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Study on the Effects of the Modulator Output Ripple on the RF System of the KOMAC 100-MeV Proton Linear Accelerator

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1. Introduction

A 100-MeV proton linear accelerator has been operating since 2013 at Korea Multi-Purpose Accelerator Complex (KOMAC). The number of users from 2013 to the end of 2015 was 656 and the number of samples irradiated with proton beam was 5,058. The high power system of the proton linear accelerator consists of accelerating cavities such as Radio Frequency Quadrupole (RFQ) and Drift Tube Linac (DTL), high power radio frequency (RF) systems such as klystrons, RF transmission lines and modulators as a klystron power supply. The modulator used at KOMAC adopted a high frequency switching technology using a 3-phase full bridge converter topology to produce 5.8 MW peak power at -105 kV with 9 % duty and produces a current ripple corresponding to the harmonics of the switching frequency. In this paper, the output ripple from the modulator is analyzed and its effects on the high power RF system are presented.

2. Modulator Output Ripple

2.1 Modulator Topology

The modulator uses a new technology based on the 3-phase full bridge converter. 12 ea. Insulated Gate Bipolar Transistors (IGBTs) are used. The switching frequency of each IGBT is 20 kHz. The IGBT switches 2.2 kV line voltages, which is stored in the two sets of 1.6 mF energy storage capacitors. The output voltage from the full bridge converters increases up to -105 kV through the pulse transformers, whose core was made by the FineMat to reduce the core loss at high frequency. There are 4 sets of modulators installed at KOMAC to drive 11 sets of klystrons. Each of 3 sets of the modulator is driving 2 sets of klystron simultaneously and the last one is driving 3 sets of klystron.

2.2 Output Signal

The output signal of the modulator is shown in Fig. 1. It corresponds to the second modulator (M02) which drives two klystrons (K101, K102). The yellow signal (Ch1) is the output voltage signal and the red one (Ch2) is the total current signal from the modulator. The other two signals (blue one and green one, Ch3 and Ch4 respectively) show the current signals to each klystron. The voltage and total current signal were measured by the voltage dividing resistors and current transformer located inside the oil tank of the modulator and the current signals to each klystron were measured by the Rogowski coil located in the klystron gallery. In Fig.1, The output voltage was -95.4 kV, total current was 50.3 A with 1 ms pulse width. The details of the pulse at flat top are shown in Fig. 2. The ripple is shown clearly in the current pulse, but it is not clear in voltage pulse because a low pass filter was installed in the voltage signal conditioner. That is why the voltage rising time is relatively slower than the current pulse rising time. The peak to peak ripple of the current pulse was 22.8 %. The signal was Fourier transformed to identify the frequency components and the result is shown in Fig. 3. The harmonics of 20 kHz, which is the switching frequency of the IGBT, are the main components of the spectrum. And the contribution of 60 kHz is most effective.

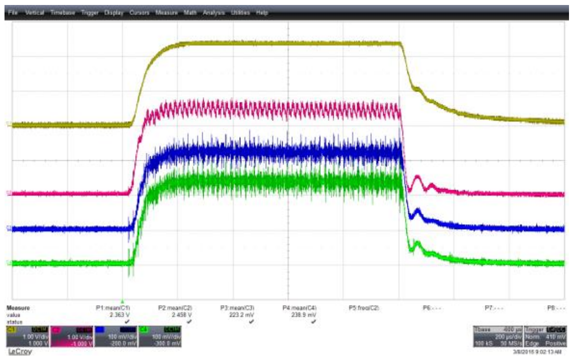

Fig. 1; Modulator pulse signal (Ch1: Voltage, Ch2: Total current, Ch3: Klystron101 current, Ch4: Klystron 102 current)

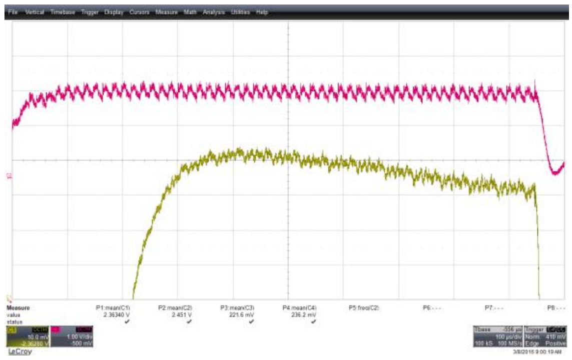

Fig. 2; Ch1: Voltage, Ch2: Total current

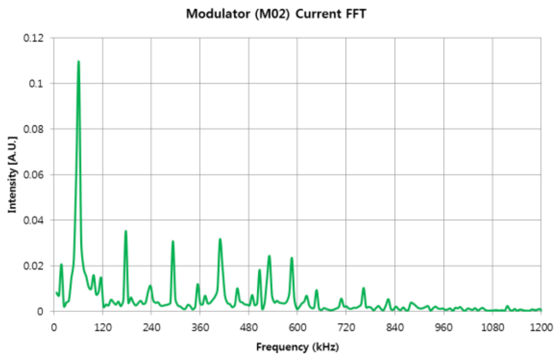

Fig. 3; Frequency Components of the Modulator Current

3. Effects on the Klystron Output Signal

The electron beam current from the electron gun of the klystron is proportional to the applied voltage with a power of 1.5 [1]. The proportional constant is called a perveance of the electron gun. For KOMAC klystron, the perveance is 1.4 μ perv. . Therefore the output RF power of the klystron is proportional to the applied voltage with the power of 2.5. The measured RF signal from the DTL pick up is shown in Fig. 4. It has a ripple clearly which has higher harmonics of the 20 kHz and the dominant component is 60 kHz as shown in the Fig. 5. The peak to peak ripple in terms of the RF voltage is 6.7 %.

Fig. 4. Measured RF amplitude ripple from DTL

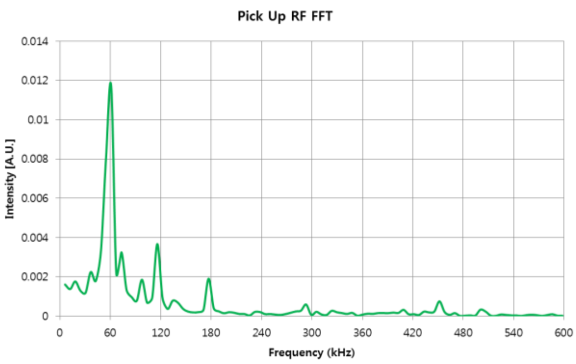

Fig. 5. Frequency Components of the RF Amplitude

3. Conclusions

The ripple current of the modulator was measured and analyzed. The higher harmonics of the switching frequency were measured and the dominant one was the third harmonic. And this ripple had an effect on the RF signal which was amplified through the klystron and delivered to the DTL. The dominant ripple component of the RF signal was also the third harmonics of the IGBT switching frequency of the modulator. The feedback control of the low level RF control system should be carefully checked and optimized to reduce the ripple components of the RF amplitude.

REFERENCES

[1] M. J. Smith, G. Phillips, Power Klystrons Today, John Wiley & Sons Inc., New York, pp.95-99, 1995.