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INITIAL HIGH POWER RF DRIVING TEST USING DIGITAL LLRF FOR RF CONDITIONING OF 1 MeV/n RFQ AT KOMAC*

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Abstract

As a part of R&D toward the RFQ(Radio Frequency Quadrupole) based heavy ion irradiation system, the 1 MeV/n RFQ was designed, brazed, installed and commissioned by staff researchers and engineers at KOMAC (Korea Multi-purpose Accelerator Complex) of KAERI (Korea Atomic Energy Research Institute). This 1 MeV/n RFQ system includes the microwave ion source, EBIS, RFQ, quadrupole magnets, switching magnet and the target systems.

The digital based LLRF (Low-Level RF) was developed to provide the stable accelerating field to the RFQ. This LLRF has features such as direct RF detection/generation without mixer, non-IQ sampling, PI feedback control, iterative learning based feed-forward control, and the digital RF interlock.

In this paper, the characteristics of LLRF are described, as well as the processes and results of an initial RF driving test for the RFQ's RF conditioning.

INTRODUCTION

The 1 MeV/n RFQ was installed at KOMAC site as shown in Fig. 1.

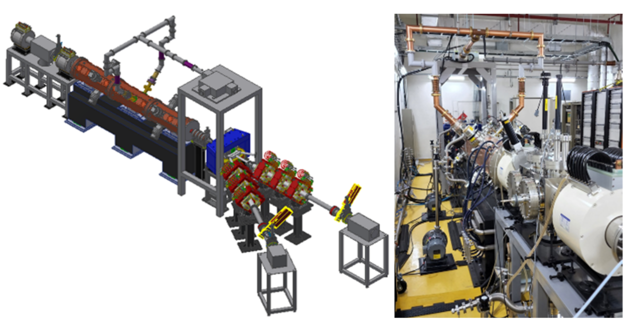

Figure 1: 1 MeV/n RFQ layout and installation.

The first beam acceleration experiment using 1 MeV/n RFQ was conducted successfully in August 2022. The LLRF commissioning and the high power RF driving test were completed before this beam experiment.

The digital LLRF was developed as shown in Refs. [1, 2]. Thanks to the configuration of the digital LLRF, we were able to achieve the simplification of analog parts such as eliminating analog mixer. As shown in Fig. 2, the sampling frequency of ADC(Analog to Digital Converter) is 320 MHz to detect the 200 MHz RF field using non-IQ sampling technic.

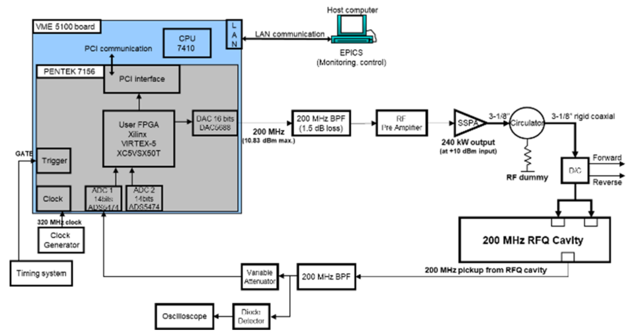

Figure 2: 1 MeV/n RFQ RF chain diagram.

A TOMCO 240 kW_{peak} SSA(Solid State Amplifier) is used as a high power RF source as shown in Fig. 3. The SSA's 240 kW_{peak} output was demonstrated using a dummy load. After that, the RFQ cavity's RF conditioning was successfully carried out up to 125 kW_{peak} until now.

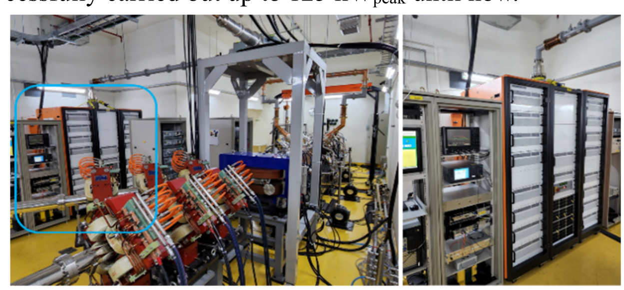

Figure 3: High power RF source installation.

LLRF UPGRADE

To compensate the heavy beam loading effect, the feed-forward control logic is essential part in the LLRF algorithm [3-5]. The parallel type ILC(Iterative Learning Control) logic was implemented in the FPGA(Field Programmable Gate Array) of digital LLRF. As shown in Fig. 4, in case of an abnormal circumstance where the RF field in the cavity becomes unstable, this logic has a feature to bypass the learning data using 2x1 multiplexer. As described in Ref. [6], this was made possible via digital RF interlock logic using a cavity pickup signal.

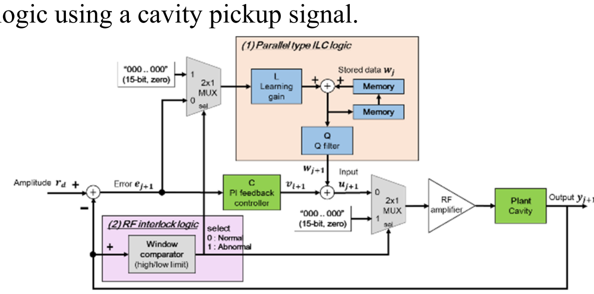

Figure 4: Implemented feed-forward control diagram.

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This ILC logic was verified in the LLRF test stand as shown in Fig. 5.

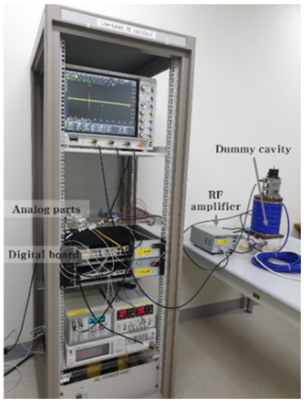

Figure 5: LLRF test stand setup..

The transient response of a heavy beam loading was immediately compensated with a few iterations because of the fast processing capability of the FPGA, as illustrated in Fig. 6. These results show that ILC with feedback control is capable of compensating for transient response to the same extent as feedback control without transient response.

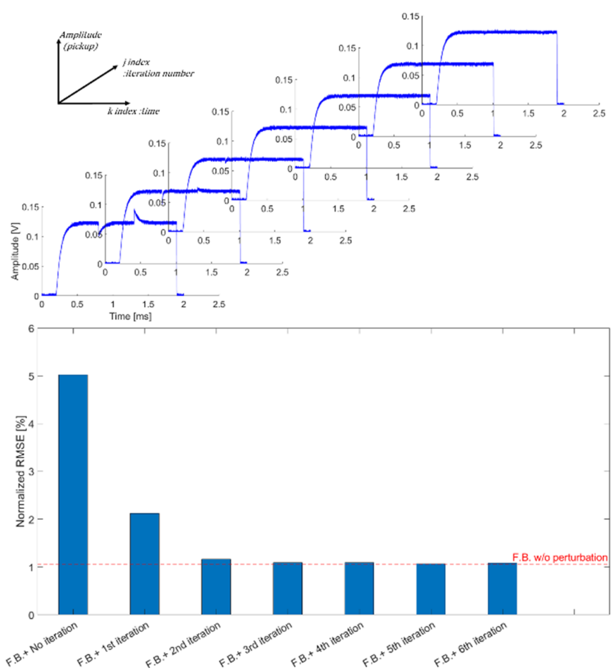

Figure 6: ILC logic test results

HIGH POWER RF DRIVING TEST

RF Source Driving Test with Dummy Load

To demonstrate the performance of the RF source, the SSA driving test was conducted using dummy load. This experiment was executed prior to the installation of RFQ cavity that the 50 ohm dummy load was used with the RF circulator as shown in Fig. 7.

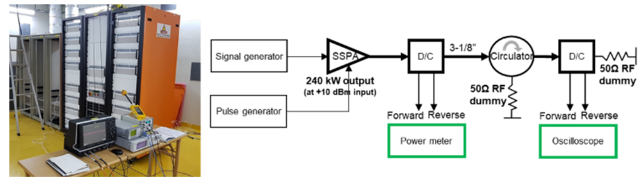

Figure 7: RF source driving test setup.

The test results are shown in Fig.8. The RF pulse width was 0.5ms and the repetition rate was 100 Hz.

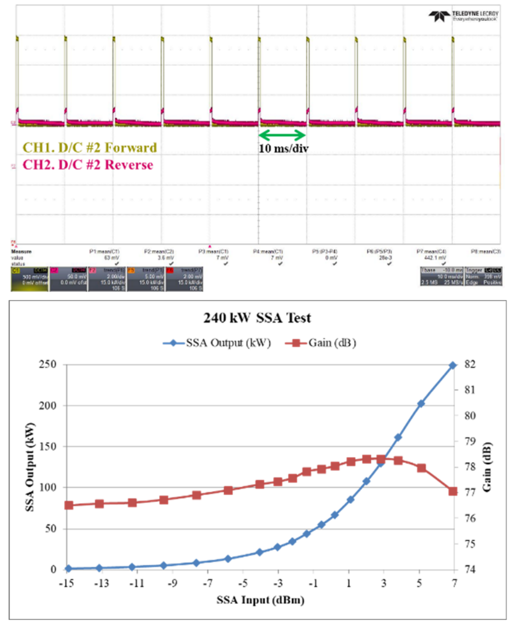

Figure 8: SSA test results.

Coupling Coefficient Measurement

After completing the SSA driving test with dummy load, the 3-1/8 inch rigid coaxial lines and the directional couplers were installed in the RF distribution system. Also, in order to confirm the coupling coefficient of the pickup port, the measuring test using the network analyser was set up as illustrated in Fig. 9. The results were used for calculating the RF power in the cavity.

RF Conditioning of RFQ Cavity

In order to generate the stable RF field for the first beam acceleration test, the RF conditioning was carried out. In the RF conditioning process, the vacuum level was meticulously monitored. As a result, 125 kW_{peak}, 0.1ms, 1 Hz RF pulse was stably generated in the cavity as shown in Fig. 10.

FUTURE WORK

In order to apply the ILC algorithm to the 1 MeV/n RFQ system, the consideration of the loop delay in the RF chain is a critical point. According to the MATLAB with Simulink simulation, it has been confirmed that the presence of time delays in the control loop (Fig. 11) can lead to diverge the system as shown in the Appendix.

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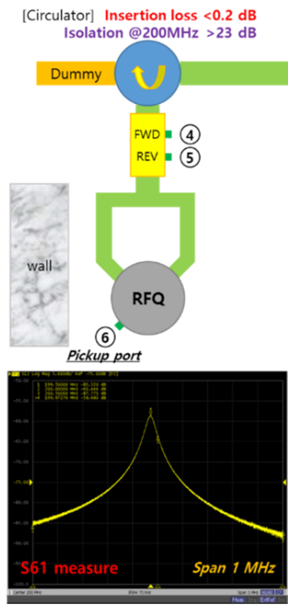

	199 MHz	200MHz	201 MHz
S21	-64.255 dB	-64.245 dB	-64.120 dB
S31	-85.4502 dB	-92.838 dB	-98.900 dB
S41	-64.932 dB	-64.869 dB	-64.389 dB
S51	-64.755 dB	-66.218 dB	-64.293 dB
S61	-90.000 dB	-63.384 dB	-97.885 dB
S56	-110.00 dB	-110.00 dB	-108.00 dB
S46	-109.80 dB	-104.38 dB	-110.82 dB
S36	-109.81 dB	-111.10 dB	-109.66 dB
S26	-115.66 dB	-110.34 dB	-111.80 dB
S16	-109.20 dB	-101.31 dB	-110.90 dB

Figure 9: Measuring coupling coefficient.

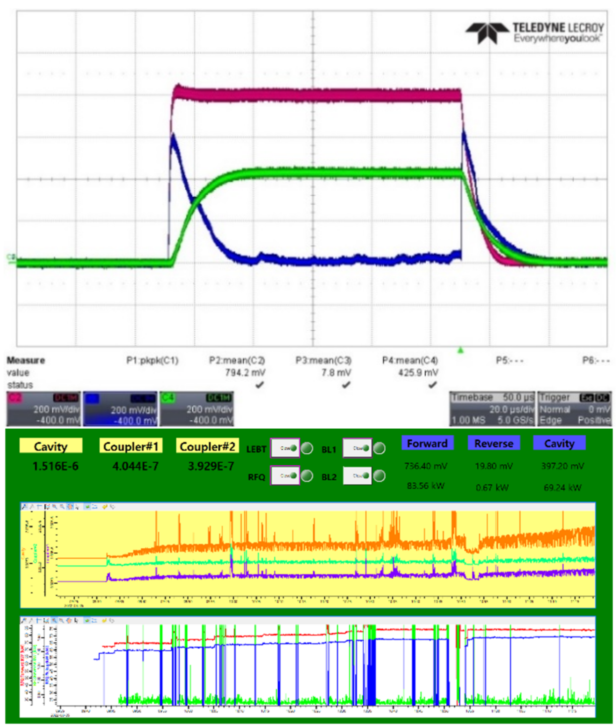

Figure 10: Results of RF conditioning.

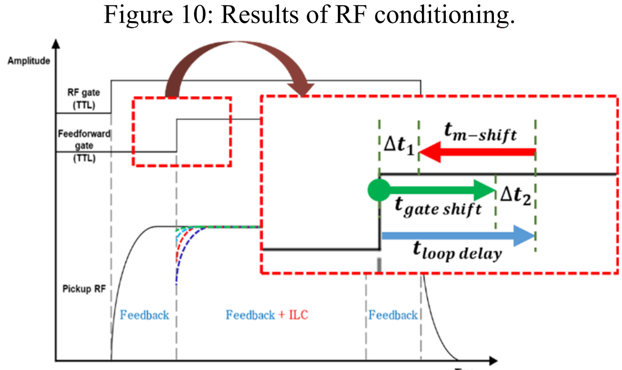

Figure 11: Time delay in the control loop.

CONCLUSION

The initial 1 MeV/n RFQ beam acceleration experiment has been successfully finished. Prior to the beam acceleration test, the RF conditioning as well as a digital LLRF upgrade and an RF source verification experiment were carried out. In near future, in-depth study on the ILC will be conducted to upgrade the digital LLRF system.

ACKNOWLEDGEMENT

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APPENDIX

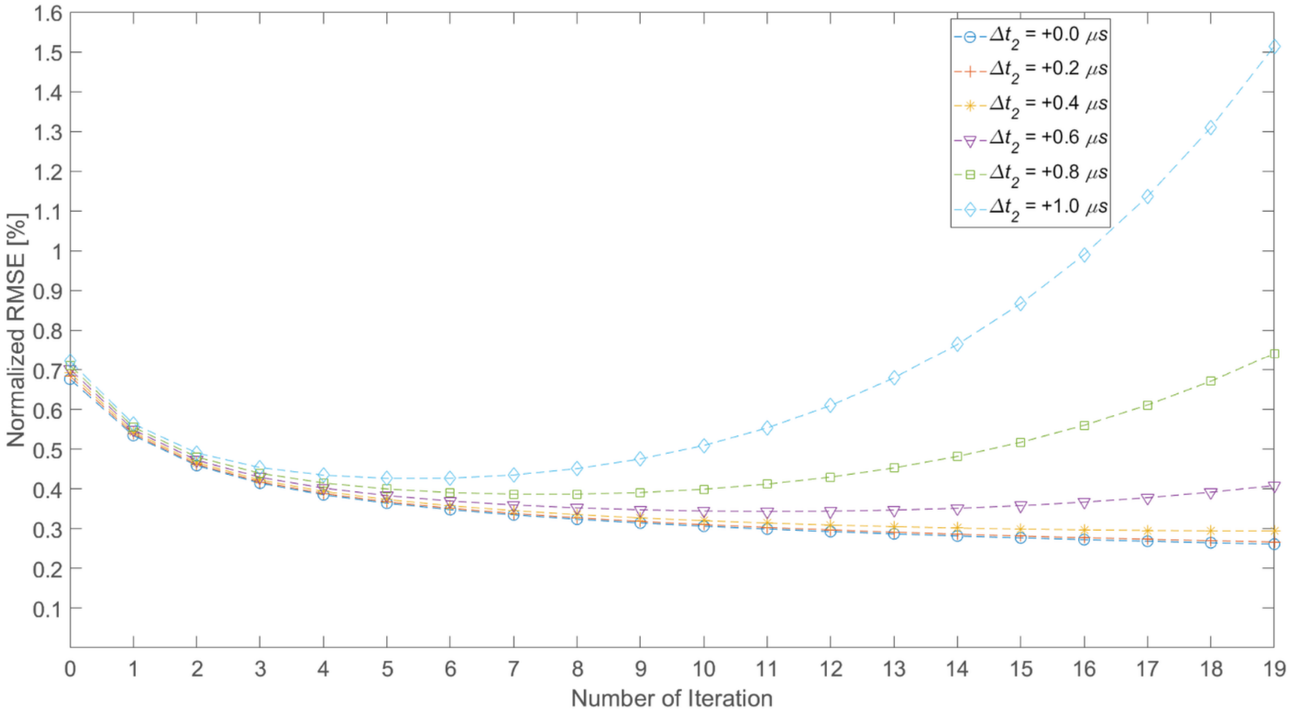

Figure A.1: Results of the simulation study on time delay effect on ILC.