PERFORMANCE OF RF SYSTEM FOR COMPACT ERL INJECTOR IN KEK

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Abstract

The construction of the compact Energy Recovery Linac (cERL) injector in KEK was finished in April 2013, following which the beam commissioning has been performed for 2 months. The cERL injector consists of a normal conducting buncher cavity (BUN) and three superconducting (SC) 2-cell cavities with double couplers. The BUN and the first SC cavity (CAV1) are driven by individual Radio Frequency (RF) power source, respectively. The second and third SC cavities (CAV2 and CAV3) are driven by one klystron using vector-sum control. The low-level RF (LLRF) system is based on I/Q (in-phase, quadrature-phase) digital feedback. RF stabilities of amplitude and phase are, respectively, 0.05%rms and 0.06°rms for BUN and 0.01%rms and 0.02°rms for CAV1, CAV2 and CAV3. Finally, the RF stability was confirmed through the measurement of the beam momentum jitter using a small current and short beam. A momentum jitter of 0.006% was achieved.

INTRODUCTION

The construction of a compact Energy Recovery Linac (cERL) is ongoing as a test facility for the 3-GeV ERL planned for the future. The construction of the injector[1] was finished in April 2013. The construction of the entire cERL will be completed by mid-December 2013. The cERL injector consists of a normal conducting buncher cavity (BUN) and three superconducting (SC) 2-cell cavities with double couplers, as shown in Fig.1. Three RF power sources are used for driving 4 cavities. The phase of the first cavity (CAV1), where the Lorentz β is low, should be changed independently from the second and third cavities (CAV2 and CAV3) in order to suppress the beam dispersion due to the space charge effect. Hence, CAV1 is driven by an independent RF source. CAV2 and CAV3 are driven together by the vector-sum operation. A power distribution system was constructed while taking into consideration the phase matching of top and bottom couplers or phase adjustment between CAV2 and CAV3 for beam transit time. The low-level RF (LLRF) system is based on IQ digital feedback using the FPGA (field-programmable gate array). The requirements of the RF stability for cERL are 0.1% rms in amplitude and 0.1° rms in phase. The requirements for 3GeV ERL are 0.01%rms in amplitude and 0.01° rms in phase. The beam commissioning has been performed for 2 months from the end of April 2013. The beam is accelerated up to 5.5 MeV by the injector. The RF stabilities and the momentum jitter of the beam were measured during this commissioning.

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HIGH LEVEL RF SYSTEM

Figure 1 shows the configuration of the RF sources[2] of the injector. RF frequency is 1.3 GHz. The BUN is driven by a 20-kW inductive output tube (IOT), and CAV1 is driven by a 25-kW klystron. Both CAV2 and CAV3 are driven by a 300-kW klystron with vector-sum operation. In order to adjust the phase between CAV2 and CAV3 for the beam, a phase shifter is located in the line of CAV3 at the outside of the shield, as shown in Fig. 2. The circulators are placed for each cavity line. Each SC cavity has two input-couplers symmetrically equipped to the top and bottom. The RF power, therefore, should be fed at the same phase.

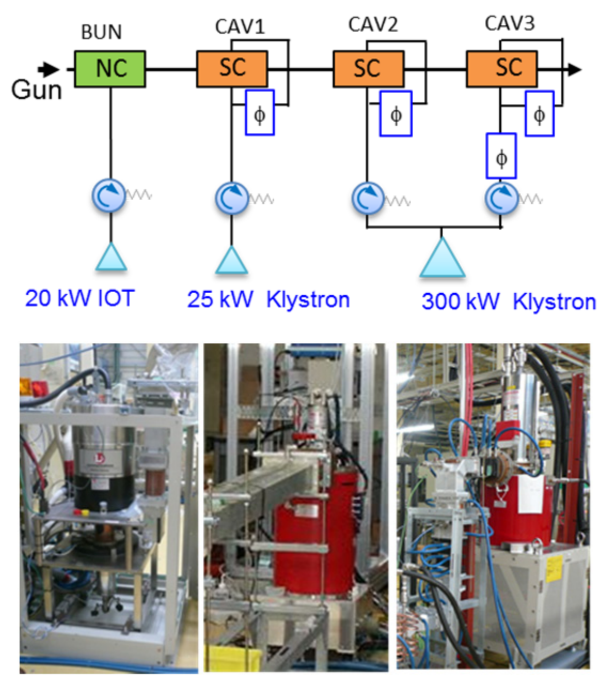

Figure 1: Configuration of RF sources of injector.

Figure 3 shows the power distribution layout feeding the injection cavity on the inside of the shielding-wall. The RF power from the RF-source is divided by the magic-T. The divided power distributed to each coupler. The length of waveguide is designed in advance. The phase shifter,

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placed at the bottom line, is adjusted to maximize the cavity field using a network analyzer.

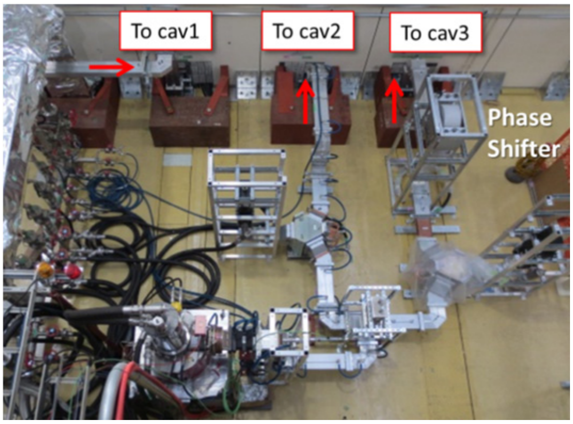

Figure 2: Power distribution system of 300-kW klystron on the outside of the shielding-wall.

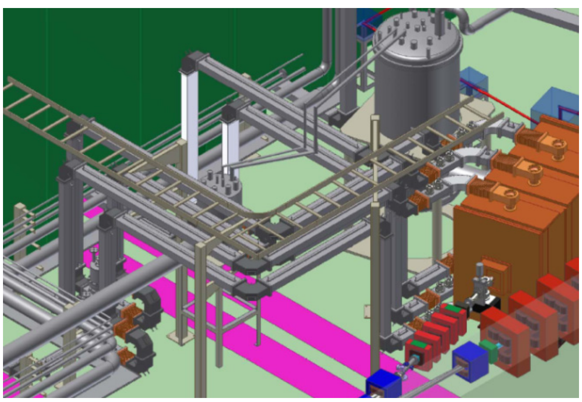

Figure 3: Power distribution layout to feed injection cavity on the inside of the shielding-wall.

LOW LEVEL RF SYSTEM

Figure 4: LLRF control racks.

Figure 4 shows a photograph of the LLRF control racks. The master oscillator (MO) and local oscillator (LO) generation system are installed inside the thermostatic chamber. The stability of the temperature inside the thermostatic chamber is 0.03°C.

Figure 5 shows a schematic of the low level RF (LLRF) digital feedback system[3]. The cavity pick-up signal of 1.3 GHz is down-converted to an intermediate frequency (IF) of 10 MHz. The IF is sampled at 80 MHz by a 16-bit ADC (LTC2208) using the μTCA digital feedback board[4,5]. The calculation in FPGA (Virtex 5 FXT) is performed by 160 MHz clock for short latency. The sampled data are separated into I/Q components. The vector-sum calculation is performed after the correction of the amplitude and the phase for the I/Q. After the I/Q data are passed through the IIR digital low-pass filter, the feedback calculation for PI control is performed. The baseband signals of I/Q from DACs (AD9783) are fed to the IQ modulator. Finally, the amplified 1.3-GHz RF signal is fed to the cavity. The feedback board is prepared for each RF source, and named FB0, FB1, and FB2 (BUN:FB0, CAV1:FB1, Vector-sum:FB2).

The digital board for tuner control[6] is prepared for each cavity. The hard-ware of the tuner board is the same as that for the feedback board, but the logic of FPGA is different from each other. The pulses for the control of the stepping motor are the outputs from the digital I/O. The signal for piezo control is the output from DAC. For the commissioning, the tuner was controlled by slow piezo-feedback through EPICS. Figure 6 shows a typical piezo control panel using CSS that displays information such as a DAC value, phase difference between input-RF and cavity-RF, and piezo voltage.

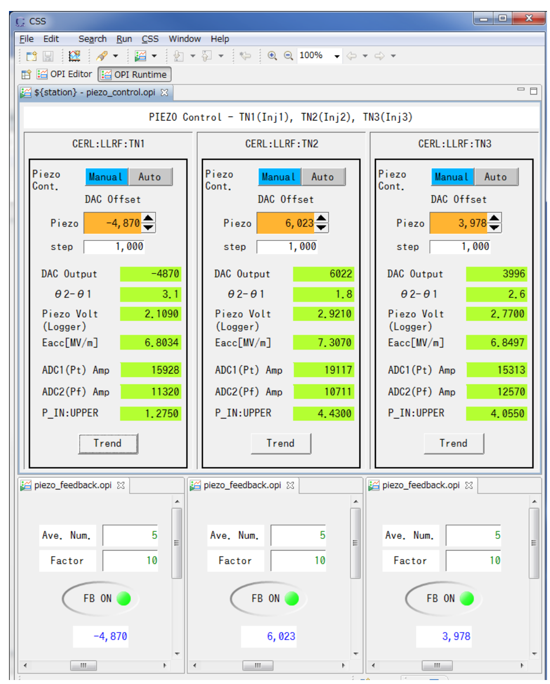

Figure 6: Piezo tuner control panel.

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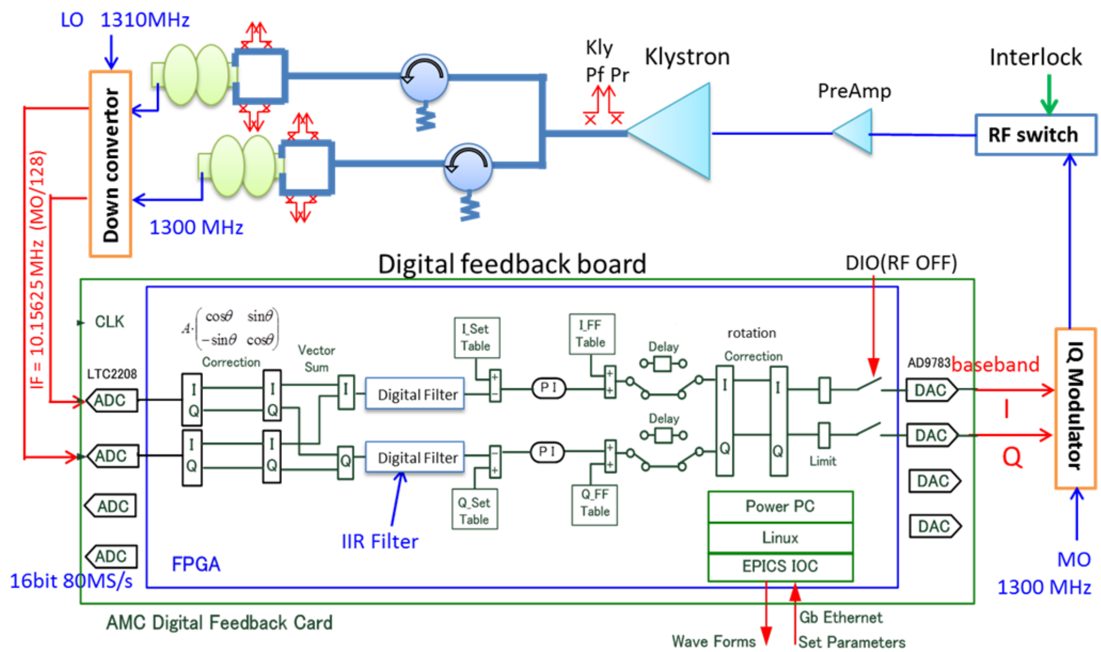

Figure 5: LLRF digital feedback system.

RF STABILITY

RF operational parameters in this commissioning are shown in Table 1. The field SC cavity field was limited to 7 MV/m because of the heating of the higher-order-mode couplers. The optimal gain was determined through a feedback gain scan[7]. Figure 7 shows I/Q data, and Fig. 8 shows the amplitude and phase data of vector-sum in FB2. A ripple of 300 Hz was observed in the data shown in Fig. 8. The ripple is caused by the DC power supply of the 300-kW klystron. However, the ripple was suppressed by FB, and RF stabilities of amplitude and phase are, respectively, 0.05% rms and 0.06° rms for BUN, 0.01% rms and 0.02° rms for CAV1, and vector-sum (CAV2 and CAV3). All systems satisfied the required stability criteria.

Table 1: Typical parameters for this commissioning

	BUN	CAV1	CAV2	CAV3
Type	NC	SC	SC	SC
Q_L	1.125×10^4	1.2×10^6	5.78×10^5	4.8×10^5
θ_b	−90°	0°	0°	0°
Ec		7 MV/m	7.4 MV/m	6.7 MV/m
Vc	114 kV	1.6 MV	1.7 MV	1.55 MV

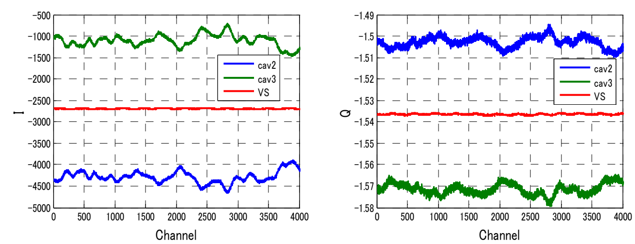

Figure 7: Waveforms for I (left) and Q (right) components in FB2 vector-sum control. Blue:CAV2, green:CAV3, red: vector-sum. (100 kS/s).

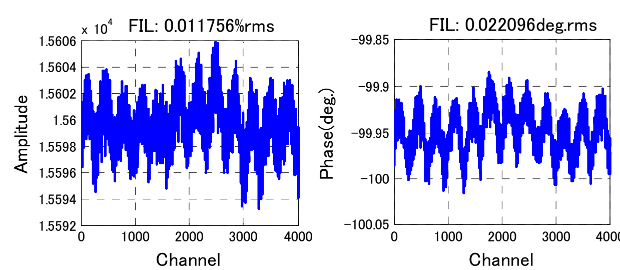

Figure 8: Amplitude and phase data in high-gain feedback for FB2 (vector-sum). (100 kS/s).

STABILITY OF BEAM MOMENTUM

The stability of beam momentum was measured using a screen monitor located downstream of the bending magnet where the dispersion is 0.82 m. The resolution is 53.4 µm/pixel. The beam conditions were very small current and short bunch (5 Hz, 0.77 pC/bunch, bunch

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length = 3 ps rms, macro pulse = 1μs). Therefore, BUN was turned off in this measurement. The momentum jitter was determined by plotting the peak point of the projection of the screen. In the first result, even though RF feedback was working, the momentum jitter was large (0.3%rms), as shown on the left-side of Fig. 9. Then, the phase shifter between CAV2 and CAV3, and the feedback phase were adjusted to increase the beam energy. The beam phase was adjusted to be on the crest phase in all cavities. This phase optimization corresponds to the modification of the vector-sum calibration error. The right-side of Fig. 9 shows the result of this optimization. Beam jitter was improved to 0.006% rms. Good stability of beam momentum was achieved. Therefore, it was confirmed that the RF field for the beam is sufficiently stable.

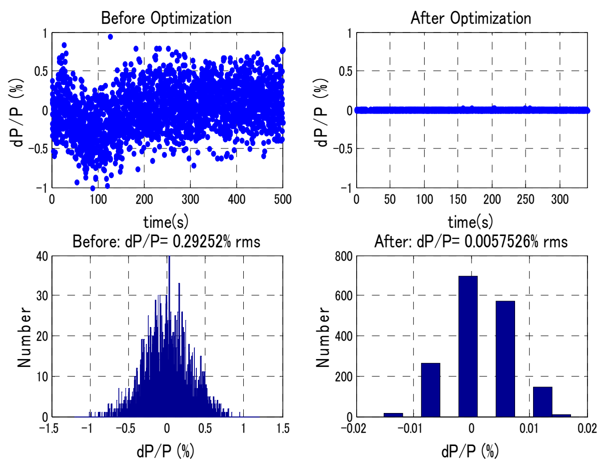

Figure 9: Beam momentum jitter. (Left: before optimization, right: after optimization).

SUMMARY

Construction of the RF system for cERL injector was completed and subsequently the commissioning has been performed for two months from the end of April 2013. RF stabilities of 0.05% rms in amplitude and 0.06° rms in phase for BUN and 0.01% rms in amplitude and 0.02° rms in phase for CAV1 and the vector-sum were achieved. RF fields satisfied the required stability. The beam momentum jitter was 0.006% rms. Good RF stability was confirmed by this result.

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