HIGH POWER TESTS OF INJECTOR CRYOMODULE FOR COMPACT-ERL

E. Kako#, D. Arakawa, K. Hara, T. Honma, H. Katagiri, Y. Kojima, Y. Kondo, S. Michizono, T. Miura, H. Nakai, H. Nakajima, K. Nakanishi, S. Noguchi, T. Shishido, T. Takenaka, K. Watanabe, Y. Yamamoto, KEK, Tsukuba, Japan
H. Hara, H. Hitomi, K. Sennyu, MHI, Mihara, Japan

Abstract

Construction of an injector cryomodule for compact energy-recovery linac (cERL) at KEK was completed. Cool-down tests, low power RF tests and high power RF tests of the injector cryomodule were successfully carried out, prior to a beam commissioning.

INTRODUCTION

Construction of compact-ERL (cERL) light-source is now in progress at KEK [1], in order to demonstrate excellent ERL performances for the future project. An injector cryomodule for the cERL is required to accelerate CW electron beams of 10 mA from the beam energy of 500 keV to 5 MeV. The cryomodule contains three 2-cell cavities equipped with two input couplers and five HOM couplers. The operating accelerating gradient (E_{acc}) of the 2-cell cavities is 6.5~7.6 MV/m in CW operation, as shown in Table 1. The vertical tests of three 2-cell cavities to qualify the cavity performance were carried out. Accelerating gradients higher than 20 MV/m [2], which exceeds an operating gradient as a cERL injector, were achieved in three cavities. RF conditioning of six input couplers at a test stand were performed with a high power RF source of 300 kW, CW. The conditioning was carefully carried out up to 200 kW in a short pulsed operation with a duty of less than 1 % and 40 kW in a CW operation [3]. Assembly of the injector cryomodule [4] was started in April, 2012. The whole assembly of the cryomodule was completed and was installed in July, 2012. The first cool-down tests for low RF power measurements was carried out in September, 2012. The second cool-down tests for high RF power measurements was carried out in February, 2013. Beam commissioning of the injector section [5] has just started in April, 2013. The results obtained in these experiments are discussed in this paper.

ASSEMBLY OF CRYOMODULE

All components like input couplers, beam tubes, RF feedthroughs and vacuum parts were carefully rinsed, and they were dried in a class-10 clean room. Every fifteen RF feedthroughs for HOM couplers were replaced with new type of feedthroughs [2]. Six input couplers were mounted in the upper and lower ports of three 2-cell cavities. Three cavities were stringed with two interconnected bellows, and two beam tubes were attached in the both end. The completed cavity string assembly is shown in Figure 1. Attachment of a frequency tuning system and alignment of three cavities were carried out. After the cold mass assembly like a cooling pipeline of 2K-He, two reservoir panels of 5K-He and thermal shields of 80K-N_2, the string cavities are inserted into the vacuum vessel. Then, the injector cryomodule was installed in the beam line and was connected with a cold valve box, as shown in Figure 2.

Table 1: Main Specification of cERL Injector Cryomodule

	Cavity - 1	Cavity - 2	Cavity - 3
V_c	1.5 MV	1.75 MV	1.75 MV
E_{acc}	6.5 MV/m	7.6 MV/m	7.6 MV/m
Q_L (10 mA)	7.2 x 10^5	8.4 x 10^5	8.4 x 10^5
P_{RF} (10 mA)	15 kW	17.5 kW	17.5 kW
RF Source	Kly-1 / 30kW,CW	Kly-2 / 300kW,CW	

Here, V_c is an accelerating voltage. Q_L is an optimum loaded Q matched with a beam current of 10 mA. P_{RF} is a required RF power per cavity. RF source of Kly-2 drives two cavities.

Figure 1: String assembly of three 2-cell cavities with six input couplers in a class-10 clean room.

Figure 2: Installation of completed cERL injector cryomodule on beam line at injector section.

#eiji.kako@kek.jp

COOL-DOWN TESTS

Prior to cool-down, RF conditioning of three pairs of top and bottom input couplers was carried out up to 20 kW, CW per coupler at room temperature. Figure 3 shows temperature changes at the cavity during thermal cycles in cool-down tests. Our cryogenic system has to be stopped at every night and during weekend, so that the cavity temperature goes up naturally due to static heat loads. After cool-down from 300 K to 2 K for 2 weeks, low power RF tests for one week and high power RF tests for two weeks were carried out. Temperature distribution around 2K-cavities, 5K-reservoir panels and 80K-thermal shields was measured by thermometry system (48Cernox, 12 Pt-Co and 36 CC). Static heat loads at 2 K and 4.2 K were measured by evaporated He-gas flow. The obtained static heat loads were 11 W at 2 K and 36 W at 4.2 K, (14 W at 2 K and 33 W at 4.2 K in estimation).

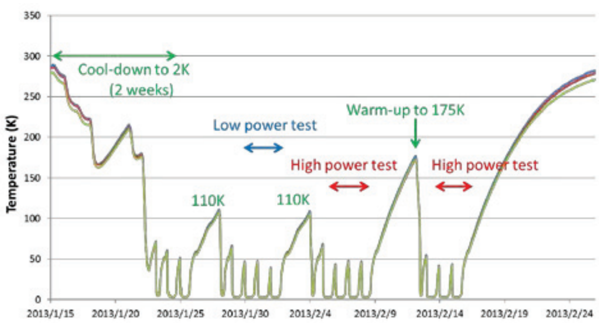

Figure 3: Cavity temperature during cool-down tests.

LOW POWER RF TESTS

Frequency tuning system consists of a slide-jack tuner for a coarse adjustment and a piezo tuner for a fine tuning. Their tuner performances are shown in Figure 4. The cavity resonant frequencies in a tuner free position at 2 K were 1299.88 MHz, 1299.65 MHz and 1299.61 MHz in three cavities, and the frequency was fairy adjusted to 1300.00 MHz by rotation of a drive shaft. The sensitivity of the frequency change (Δf) was 20 kHz/rotation and 1000 kHz/mm in a cavity length. A pair of high-voltage-type piezo element was attached at the both side of the slide-jack tuner. Two piezos are operated simultaneously by one driver amplifier. The range of the frequency change (Δf) was 2 kHz by an applied voltage of +500 V, DC. Feedback control of the piezo tuner against frequency changes will be introduced in a beam commissioning.

Measured external Q values are summarized in Table 2. After the phase adjustment between top and bottom input couplers, the loaded Q values (Q_L) were measured. Since two cavities (2 and 3) are driven by one klystron, difference of the Q_L values between two cavities causes an unbalance of the operating E_{acc} of about 10 % in this case. It was confirmed that filter characteristics of 15 HOM couplers were well adjusted to reject an acceleration mode at 2 K.

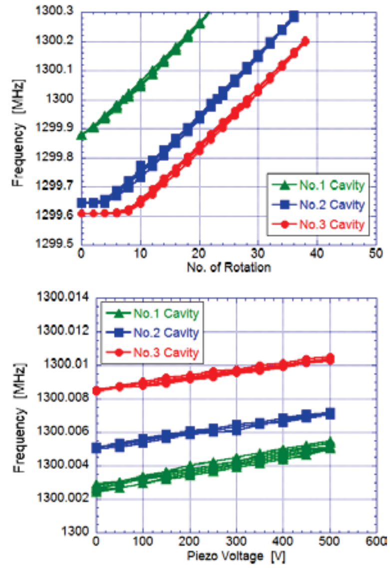

Figure 4: Tuner performance by a slide-jack tuner (top) and a piezo tuner (bottom).

Table 2: Measured External Q Values

	Cavity - 1	Cavity - 2	Cavity - 3
Q_L	1.20×10^6	5.78×10^5	4.80×10^5
Q_T	5.62×10^{10}	4.36×10^{10}	4.27×10^{10}
Q_{HOM-1}	2.90×10^{14}	2.48×10^{13}	3.72×10^{11}
Q_{HOM-2}	8.61×10^{11}	2.02×10^{12}	1.95×10^{13}
Q_{HOM-3}	1.04×10^{12}	3.34×10^{12}	9.04×10^{13}
Q_{HOM-4}	1.31×10^{12}	2.15×10^{12}	3.31×10^{12}
Q_{HOM-5}	1.02×10^{12}	4.00×10^{11}	1.58×10^{12}

Here, Q_L is a loaded Q value, Q_T is an external Q value of a monitor coupler and $Q_{HOM-1,-2,-3,-4,-5}$ are external Q values of five HOM couplers for an accelerating mode.

HIGH POWER RF TESTS

High power RF tests were carried out by the following procedure:

1. Conditioning in a single cavity operation.
2. Measurement of a dynamic heat load and Qo.
3. Simultaneous operation of three cavities.
4. First beam commissioning in injector section, [5].

The RF conditioning of the three cavities was started in a pulsed operation of 2 ms and 5 Hz, (duty = 1 %), and an accelerating gradient of 15 MV/m was successfully achieved. Then, the duty factor was increased to 10 %, (50 ms and 2 Hz), as shown in Figure 5. Finally, a stable CW operation at 8 MV/m was confirmed. Observed results of x-rays radiation level at a beam tube is shown in Figure 6. The radiation levels in three cavities were about 0.1~3.0 mSv/H at 15 MV/m in a pulsed operation (duty 10 %), and there was no detection at less than 10 MV/m. No x-rays radiation in a CW operation at 8 MV/m was confirmed in all of the three cavities.

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Measured dynamic heat loads (cavity RF loss, P_o) in three cavities are shown in Figure 7. An estimation of a heat load is calculated by an equation of E_{acc} = C x $(P_o{*}Q_o)^{0.5}$, C = 62.7. An estimated heat load in case of E_{acc} = 8 MV/m and $Q_o = 1.5\text{x}10^{10}$ is about 1 W at 2 K, however, the observed heat load was 10~15 W at 8 MV/m. This means one order lower Q_o values, as shown in Figure 8. The reason for the large dynamic heat load was due to heat up at RF feedthroughs of HOM couplers. Transition from superconducting to normal-conducting state was induced at the Nb antenna connected with the RF feed-throughs due to insufficient cooling. As the consequence, RF losses at the Nb antenna tip increased, and temperature rises at all of five RF feedthroughs were observed, as shown in Figure 9. Stable CW operation at 8 MV/m was confirmed in three cavities, but improvement of an efficient cooling at the RF feedthroughsh is an essential issue to reduce the dynamic heat load.

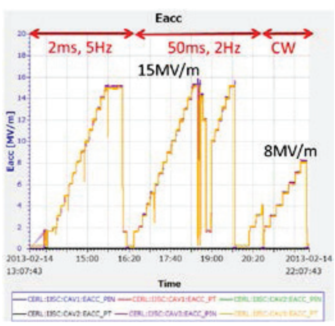

Figure 5: Accelerating gradient (E_{acc}) during high power RF conditioning in Cavity-3 at 2 K.

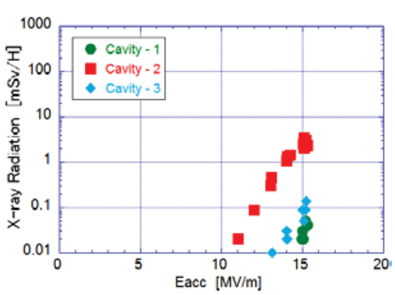

Figure 6: X-rays radiation observed in a pulsed operation with 50 ms and 2 Hz (duty 10 %) in a single cavity operation of three cavities.

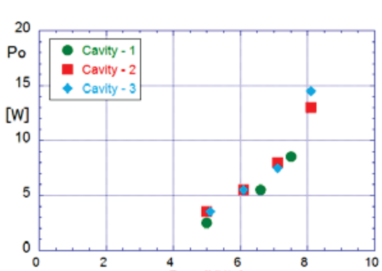

Figure 7: Cavity dynamic heat load (Po) measured by a evaporated He-gas flow at 2 K.

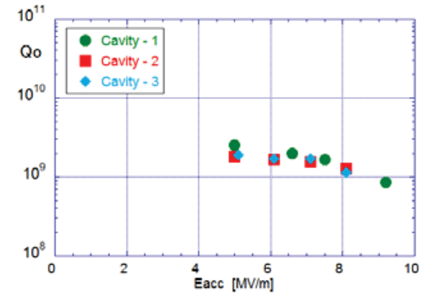

Figure 8: Measured Qo values of three cavities in a CW operation at 2 K.

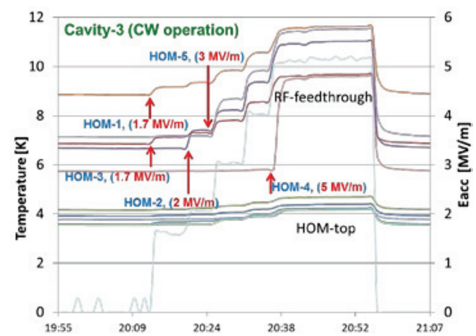

Figure 9: Observation of temperature rises at RF feedthroughs of HOM couplers due to quench at the Nb antenna tip.

SUMMARY

- A stable CW operation at 8 MV/m (7.6 MV/m in specification) without x-rays radiation was confirmed in all of three 2-cell cavities.
- Measurement of Qo values at 5–8 MV/m by dynamic heat loads at 2 K showed one order lower values than the expectation due to the heat-up at all of the HOM RF feedthroughs.

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