ASSEMBLY AND COOL-DOWN TESTS OF STF2 CRYOMODULE AT KEK

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Abstract

As the next step of the quantum beam project, the STF2 (STF; Superconducting Test Facility) project is in progress at KEK. Eight 9-cell SC cavities and one superconducting quadrupole magnet were assembled into the cryomodule called CM1. Four 9-cell SC cavities were assembled into the cryomodule called CM2a. These two cryomodules were connected as one unit, and the examination of completion by a prefectural government was performed. The target value of beam energy in the STF2 accelerator is 400 MeV with a beam current of 6 mA. The first cool down test for low power level RF measurements was performed in autumn of 2014. In this paper, the assembly procedure of the STF2 cryomodules and the results of the low-power measurement are reported.

VERTICAL TEST RESULTS

The following cavity surface treatment processes were performed before the vertical test at KEK.

1) Pre-EP 5 μm and EP-I 100 μm for the impurities layer removal
2) Annealing for 3 hours at 750 ˚C for stress relief and degassing
3) Inner surface inspection using Kyoto camera system and local grinding if defects are found
4) Finish electropolishing, EP-II 5~20 μm
5) HPWR for 5 hours with 8 MPa using ultra-pure water
6) Baking for 44 hours at 140 ˚C

Figure 1 and Figure 2 show the final vertical tests results of the cavities MHI#14~MHI#22 [1]. The vertical tests were performed 22 times in total from January, 2011 to November, 2012. MHI#14~MHI#22 cavities except MHI#16 constitute cryomodule 1 (CM1). The average value of the maximum accelerating electric field of the cavities that constitutes the CM1 was 37 MV/m.

Figure 3 shows the final vertical tests results of the cavities MHI#23~MHI#26 [1]. The vertical tests were performed 10 times in total from October, 2013 to January, 2014. MHI#23~MHI#26 cavities constitute cryomodule 2a (CM2a). The main purpose of the cavities from MHI#23 to MHI#26 is the manufacturing cost reduction [2]. The maximum accelerating electric field of the MHI#24 was 12 MV/m due to strong field emission. So, the average value of the maximum accelerating electric field of the cavities that constitutes the CM2a was 28 MV/m.

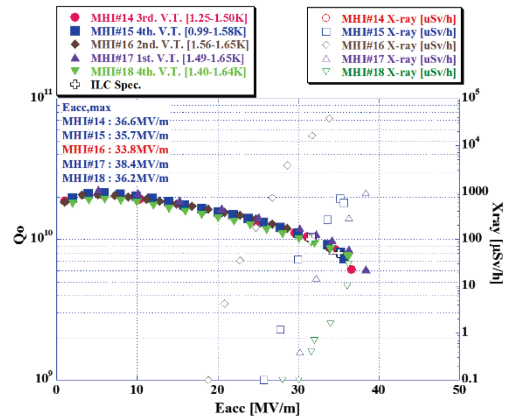

Figure 1: Final results of V.T.: MHI#14~MHI#18.

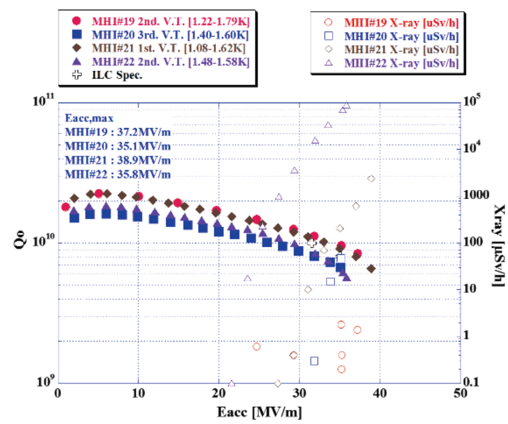

Figure 2: Final results of V.T.: MHI#19~MHI#22.

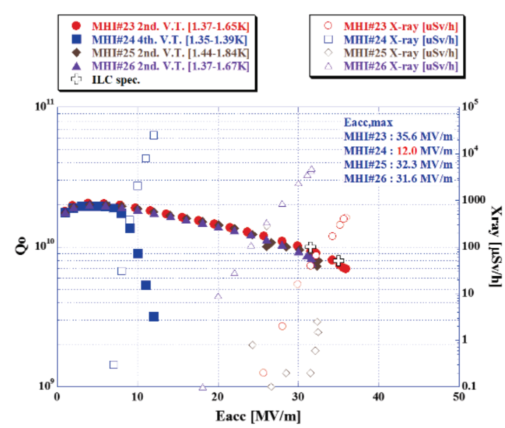

Figure 3: Final results of V.T.: MHI#23~MHI#26.

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CAVITY MODULARIZATION

Connection of the Cavities

After finishing the vertical test, cavity was purged with argon gas through a filter and was transported to MHI in order to weld the liquid helium jacket includes a tuner mounting with a bellows after having surrounded by a magnetic shield.

The cavities were transported to KEK after the welding processing was finished, and cavity connection work was started. The 4 cavities were connected in series. First, after waterproofing of key parts of the cavity jacket, high pressure water rinsing with ultrapure water in a clean booth that was adjacent to the class 1000 was performed.

Then, the cavities were moved to the class 10 cleanroom after keeping in a class 1000 cleanroom about one day for cleaning and drying. Before cavity connection work, overall cleaning was performed using an ion gun carefully. Tin plated HELICOFLEX were used for a vacuum seal. The connection of 4 cavities was performed after the installation of the input coupler in each cavities and of the gate valve at the up and down stream ends. In the process of opening the cavity in a class 10 cleanroom, it was important to prevent dust from entering the cavity by keeping a positive pressure by injecting argon gas through a filter. Then, the adjustment of the horizontal and vertical directions and the leak test of the 4 cavities was performed. The connected 4 cavities that passed the leak test was moved to the class 1000, the connection of the liquid helium supply pipe was performed (Figure 4). If passed the leak test of the liquid helium supply pipe, the connected 4 cavities was moved outside of the cleanroom.

Figure 4: String assembly of MHI#19 ~ MHI#22.

Test of Tuner Characteristic and Frequency Adjustment of HOM Couplers

At first, the movement examinations of the tuners and the characteristic confirmation of the cavities were performed. The test results of the tuner characteristic at room temperature are shown in Table 1.

Table 1: Measurement Results of the Tuner Characteristics at Room Temperature

Cavity	#14	#15	#17	#18	#19	#20	#21	#22	#24	#23	#25	#26
Reference freq. (MHz)	1297.43	1297.40	1297.37	1297.25	1297.31	1297.29	1297.37	1297.45	1297.36	1297.38	1297.50	1297.44
Δf/ΔL (kHz/mm)	301	301	309	296	299	295	316	285	290	308	332	301
Δf/rotation (kHz/rot.)	15	15	16	16	16	16	15	16	16	15	16	16
ΔL/rotation (mm/rot.)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.04	0.05	0.05
Max torque (Nm)	0.40	0.55	0.46	0.65	0.56	0.50	0.80	0.68	1.00	0.75	1.05	0.65

Then the frequency adjustment of HOM couplers was performed. The adjustment knob broke down due to inappropriate welding at the time of frequency adjustment of HOM#2 of MHI#25 (Figure 5).

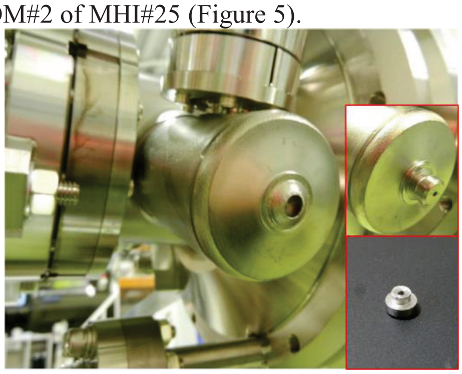

Figure 5: HOM Coupler from which the knob for frequency adjustment fell out: MHI#25 HOM#2.

The $Q_{HOM\#2}$ was about 10^{11} when a knob broke down. As a results, an improvement of the welding of the knob for frequency adjustment and an increase of the chemical polishing of HOM coupler in order to reduce the frequency adjustment range with respect to the cavity to be produced next were decided.

Insertion into the Cryostat

The two 4 cavities that had been transported into the STF tunnel were connected in a clean booth, and eight series cavities that constituted the CM1 were completed. Superconducting quadrupole magnet was installed around the center of the beam pipe. After installation of peripheral components such as RF cables, temperature sensors, heat insulations, heat shields and various piping of vacuum and cooling systems, cavities and superconducting quadrupole magnet were installed into the cryostat CM1 [3]. After having installed the 4 cavities to the cryostat CM2a on the ground, the CM2a was transported into the STF tunnel and was installed in downstream of the CM1. The two cryomodules were connected as one unit (Figure 6) and passed an examination of completion by Ibaraki prefectural government office in July, 2014.

ISBN 978-3-95450-178-6

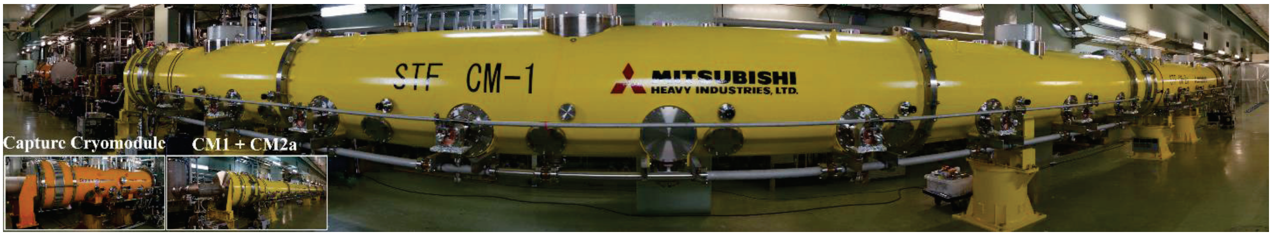

Figure 6: Capture cryomodule and CM1 + CM2a on July 31, 2014.

CAVITY COOL-DOWN

Cavity Characteristics during Cooling

Figure 7 shows the package of STF2 SC cavity system.

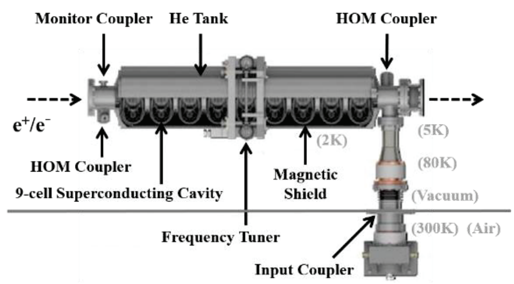

Figure 7: Cavity package of STF2 superconducting cavity system.

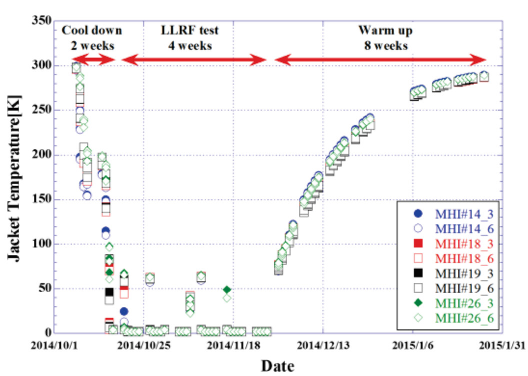

Figure 8: One cool-down/warm-up cycle for 14 weeks.

The cavity cool-down test was performed from October, 2014. Figure 8 shows the cavities temperature.

Figure 9 shows the resonant frequency of each cavities at each temperature. The horizontal axis shows an arrangement of the cavity from the electron gun side located upstream. The resonant frequency of the cavity is adjusted to 1297.2~1297.4 MHz by pretuning. In the horizontal cryomodule, resonant frequency of the cavity increases about 700 kHz in the state change from vacuum vessel (1 atm), cavity (vacuum), LHe vessel (1 atm) to vacuum vessel (vacuum), cavity (vacuum), LHe vessel (1 atm). As a result, resonant frequency at room temperature is about 1298 MHz. Frequency change due to temperature change from room temperature to 4 K is +2 MHz and frequency change due to temperature changes from 4 K to 2 K is about -300 kHz, so the resonant frequency at 2 K is 1299.7~1299.9 MHz. The difference between the resonant frequency and the operating frequency of the cavity can be adjusted by the tuner.

Figure 10 shows the loaded Q values Q_L of the cavities determined from the measured half-bandwidth with a network analyzer. The obtained external Q values of the input coupler Q_{in}, which is approximately equal to Q_L at 2 K were $3.5\sim5.4\times10^6$ and 5×10^6 of the target value was confirmed to be adjustable.

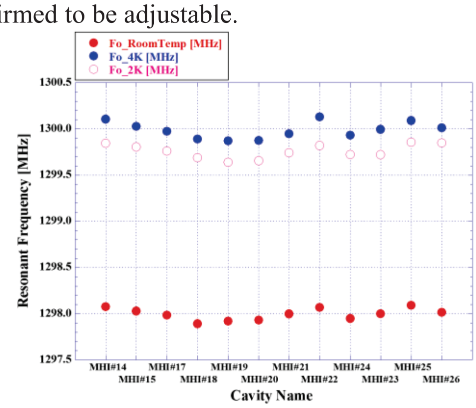

Figure 9: Resonant frequency at 300 K, 4.2 K and 2 K.

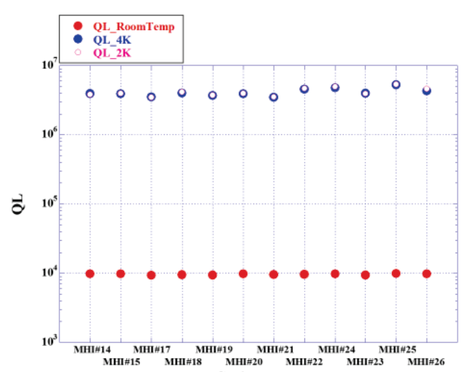

Figure 10: Loaded Q value at 300 K, 4.2 K and 2 K.

LOW POWER RF TEST

Measurements of Tuner Stroke

Figure 11 shows the slide jack tuner we have adopted. Rotating the drive shaft outside the vacuum chamber, the wedge-shaped rollers will move the inclined portion in a vertical direction. As a result, load is applied between the flanges of the bellows ends at the outer peripheral portion of the helium tank, it is possible to vary the resonant frequency by stretching in the horizontal direction within the elastic deformation range of the cavity.

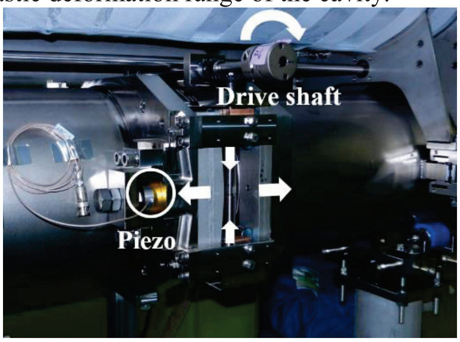

Figure 11: Frequency tuner system consisting of a slide-Jack and piezo tuner.

Figure 12 shows the resonant frequency changes of the cavity when the drive shaft for each cavities was 40 rotation. The cavity resonant frequency at 2 K is 1299.85 MHz ± 100 kHz and the frequency change by the tuner is 480~573 kHz, so the operating frequency is fully adjustable to 1.3 GHz. 40 rotations of the drive shaft corresponds to increasing 2.2 mm of the cavity length, the frequency change per 1mm is 218~260 kHz.

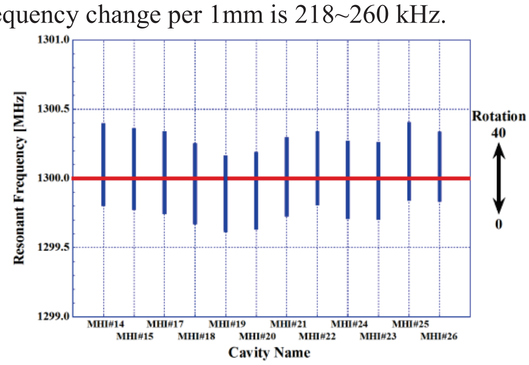

Figure 12: Tuning range of resonant frequency.

Measurement of Input Coupling Stroke

Figure 13 shows a schematic drawing of the input coupler. The input coupler is composed of a low temperature part, room temperature part and doorknob type coaxial waveguide transducer. Antenna tip of the inner conductor of the input coupler is a bellows structure, the degree of coupling between the coupler and the cavity is adjustable by changing the length (Δl).

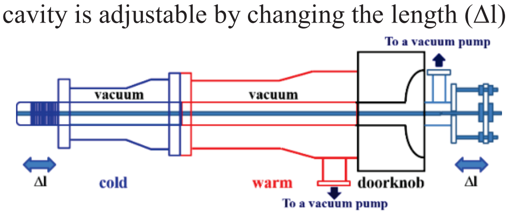

Figure 13: Schematic drawing of STF2 input coupler.

Figure 14 shows the measurement results of the external Q value (Q_{in}) of the input coupler of each cavities. Δl is the antenna tip length and the variable range of Q_{in} corresponds to the value of Q_{in} obtained from the maximum to minimum of Δl. 5×10^6 of the target value of Q_{in} was able to be set for all of the cavities.

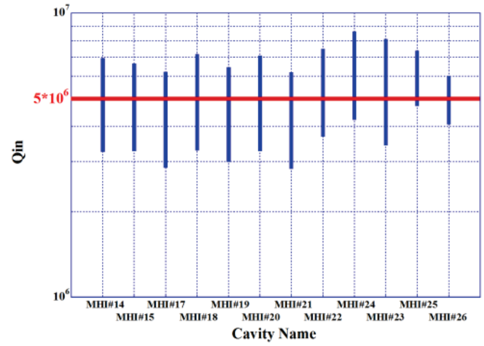

Figure 14: Coupling range of input coupler.

Measurements of External Q Value

Loaded Q values of the cavities (Q_L) were measured by three different methods. External Q values of the monitor couplers (Q_t) were obtained using the measured values of Q_L. Three methods are described below.

1) A method to get Q_L using a network analyzer, where P_G is generator power.

$$P_i Q_i = 4 P_G Q_L$$

$$Q_i = \frac{4 P_G Q_L}{P_i} = \frac{4 \times Q_L \times \text{correction factor}}{10\text{^}(S_{21}/10)}$$

$$i = \text{Monitor, HOM1, HOM2}$$

2) A method to get Q_L from cavity half bandwidth Δf using a 400 W amplifier, where f_0 is a cavity resonant frequency.

$$Q_L = \frac{f_0}{\Delta f}$$

3) A method to get Q_L using a 400 W amplifier from cavity decay time $\tau_{1/2}$.

$$Q_L = \frac{2\pi f_0 \tau_{1/2}}{\ln 2}$$

Q_t is obtained by the following equation using the Q_L.

$$Q_t = \frac{4 P_G Q_L}{P_t}$$

$$P_G = P_{in} \times \text{correction factor}$$

$$P_t = P_t / \text{correction factor}$$

Figure 15 shows the Q_L of each cavities measured by three methods. Q_L obtained by using a network analyzer were 4.8~5.2×10^6, and Q_L obtained by using a 400 W amplifier were 4.2~4.8×10^6. Q_L obtained by a network analyzer shows about 10 % greater value on average.

Figure 16 shows the Q_t of each cavities calculated from the above equation 1) ~ 3) and obtained in the vertical tests. Each values of the Q_t obtained by using a network analyzer and an amplifier are in good agreement. As for the results of vertical tests and current measurements, Q_t are consistent in the range of 25% of errors. Q_t is desirable to be about 10 times of Q_0, so the desired value becomes 1×10^{11} for Q_0=1×10^{10} at 2 K. All cavities have the desirable values Q_t.

Figure 17 shows the filter properties of the acceleration mode of the HOM couplers. Measuring and adjusting the

ISBN 978-3-95450-178-6

filter properties of HOM couplers have been performed at room temperature after connecting the cavities. External Q values of HOM couplers in the acceleration mode have been achieved $Q_{HOM}>1\times10^{11}$ in all cavities and the necessary filter properties are obtained. The filter properties of HOM couplers adjusted in room temperature have been kept after cooling at 2 K.

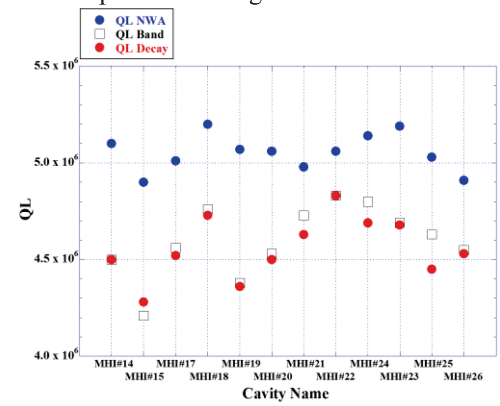

Figure 15: Comparison of the Q_L value obtained in three methods.

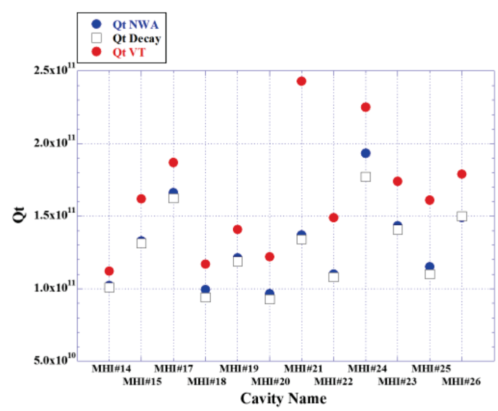

Figure 16: Calibrated value of monitor coupler.

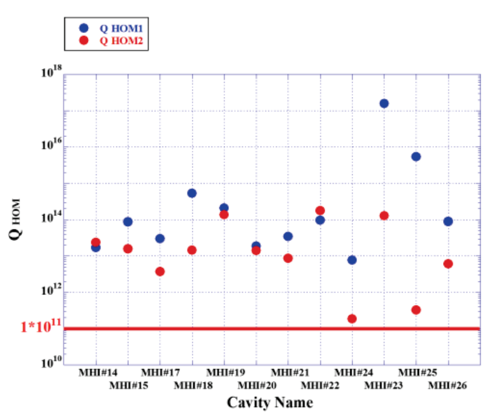

Figure 17: Filter property of HOM couplers for accelerating mode.

Measurements of Piezo Stroke

Figure 18 shows the frequency changes of each cavities in the case of applying 500 V to the piezoelectric element for compensating the Lorentz detuning.

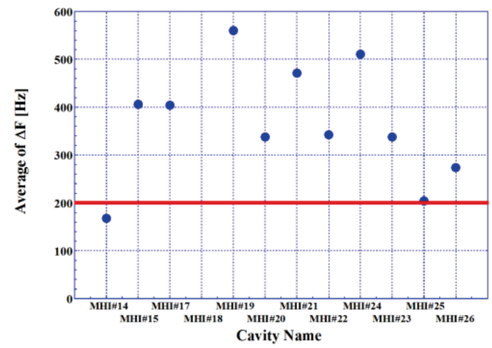

Figure 18: Variable frequency range corresponding to the piezo voltage 500 V.

The piezoelectric element of MHI#18 was damaged caused by an electric discharge during the measurements. This element was already exchanged and has been applied the voltage of 500 V. In accelerating electric field 31.5 MV/m of ILC, frequency shift of 200 Hz derived from the Lorentz de-tuning needs to be compensated. Variable frequency range more than 200 Hz was obtained in the cavities except for MHI#14, #18 and #25. Variable frequency range of MHI#14 and #25 is narrow, but by increasing the voltage up to 1 kV, sufficient variable range is considered to be obtained.

SUMMARY

The two cryomodules called CM1 and CM2a were connected as one unit. First cool-down started from October, 2014 and low power RF tests of four weeks were performed. In this test, the confirmation and the adjustment of the performance of each devices were performed. In future plan, the high power RF test in October, 2015 and the beam test with beam current 6 mA and beam energy 400 MeV is planned in 2016.

ACKNOWLEDGMENT

The authors would like to thank to those who support our tests, especially to the staffs of the KEK Cryogenic Center for supplying liquid helium. Special thanks to M. Sawabe of KEK Radiation Science Center and to the staffs of Assist Engineering Co., Ltd. for their cavity surface preparation. Special thanks also to the staffs of K-VAC Co., Ltd. and Nippon Advanced Technology for their cooperation with all the processes of cavities and cryomodules.

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