THE FIRST MEASUREMENT OF LOW-LOSS 9-CELL CAVITY IN A CRYOMODULE AT STF

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Abstract

We are constructing Superconducting RF Test Facility (STF) at KEK for the R&D of ILC accelerator. In the beginning of year 2008, we installed one high-gradient Low-Loss (LL) 9-cell cavity into a cryomodule (CM) at STF. We assembled the cavity with an input-coupler and peripherals in a clean room and the cavity package was dressed with thermal shields to be installed in a CM. At the room-temperature, we performed the processing of input-coupler up to the RF power of 350 kW. At the temperatures of 2 K, RF power was supplied from a klystron to the cavity. The lorentz force detuning of cavity was measured and the performance of the cavity packeage was tested. This article presents the results of the first test of the LL 9-cell cavity at 2 K in a CM.

INTRODUCTION

In the year of 2006, we fabricated two cryomodules A and B for Superconducting RF Test Facility (STF) [1] at KEK for the R&D of ILC accelerator. The cryomodule A (CM-A) was designed to install four TESLA-like 9-cell cavities and cryomodule B (CM-B) was for four high-gradient Low-Loss (LL) 9-cell cavities. In February 2007, we finished the installation of one TESLA-like 9-cell cavity into CM-A and one LL 9-cell cavity into CM-B, and two CM's were connected. After the evacuation and pumping inside of the CM's, a leak was found around the He pipes and He jacket of LL cavity. In order to solve the problem, two CM's were separated and only CM-A was cooled down. However, another leak was found inside the 2K-cold-box of cooling system where liquid He is produced. The leak of cooling system was fixed and only CM-A was successfully cooled down in the end of year 2007 [2]. CM-B was dismantled and rigorous test was done to find out the leaking point, but no evidence of leak was found. We decided to re-install the same LL cavity into CM-B and to cool down only CM-B. In March 2008, we successfully cooled down the CM-B.

HISTORY OF INSTALLED LL CAVITY

Descriptions for the fabrication and the inner-surface treatments of LL 9-cell cavities can be found elsewhere [3]. Before the installation of the LL 9-cell cavity into CM-B, the LL cavity was tested in a vertical-test stand eight times. Figure 1 shows the results of the last vertical test in November 2006 before the installation into CM-B. The cavity has reached the gradient of 19 MV/m at the intrinsic quality factor Q_0 of 3.6E9 where field emission and Q_0 degradation was observed above 9 MV/m.

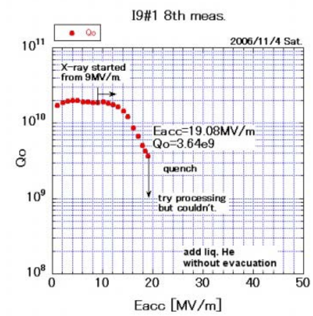

Figure 1: The results of last vertical test before installing the LL 9-cell cavity into cryomodule.

After dismantling CM-B to find out the leaking point, we tried ethanol rinse and degreasing for the LL 9-cell cavity. The concentration of degreaser (Micro-90) was 2%. After the degreasing process, High Pressure Rinse (HPR) was applied for three hours. No vertical test was done after these treatments. The LL cavity was re-assembled with an input-coupler and peripherals in a clean room and the cavity package was installed into CM-B again.

PROCESSING OF CAPACITIVE-COUPLING INPUT-COUPLER

After installing the cavity package into CM-B, the warm part of input-coupler was assembled with the cavity. The processing of capacitive-coupling input-coupler at room temperature was done successfully in February 2008. The input RF-power of 350 kW with the pulse-width of 1.5 m sec at the repetition rate of 5 pps was achieved. Details for the procedures of input-coupler assembly and processing can be found elsewhere [4].

COOLING DOWN OF CAVITY AND MEASUREMENTS OF LOADED QUALITY FACTOR

The LL cavity was successfully cooled down to the temperature of 2 K without any leakage of He on 6th

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March 2008. The installed LL cavity was equipped with stainless steel He jacket which is jointed with the Nb beam-pipes of cavity by the Hot Isostatic Pressing (HIP) bonding technology. We emphasize that this test demonstrated a possibility for the usage of cheaper stainless-steel He jacket for ILC.

The design value of loaded quality factor Q_L for the LL cavity in ILC is 2.6E6. The coupling of input-coupler to the cavity: $\beta \sim Q_0/Q_L$ can be changed in the assembly procedure by changing the length of bellows in the cold-part of coupler [4]. Considering the precisions of fabrication and assembly, we tried to set Q_L = 2.2E6 to get a wider Band-Width (BW). After cooling down the cavity, we measured the Q_L of cavity with several methods. Firstly, Q_L was estimated by measuring the BW with two different network analyzers. The results were Q_L = 1.76E6 (BW = 740 Hz) and Q_L = 1.70E6 (BW = 764 Hz). The BW was also measured by inputting low-power RF signal with changing frequency and measuring the transmitted power: Pt with a power-meter. The result was Q_L = 1.79E6 (BW = 726 Hz). Finally, the decay time of Pt was measured and the result was Q_L = 1.68E6 with the decay time (1/2) of 142 μ sec. The external Q of the field probe antenna: Qt was measured based on the formula: $Qt \sim 4 {*} Q_L {*} (Pg/Pt)$ if $\beta >> 1$, where the Pg is the generator power. The result was Qt = 1.0E12 using Q_L = 1.7E6.

PROCESSING OF CAVITY

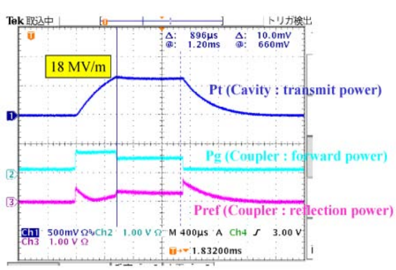

Figure 2: Pulse-shapes of transmitted power (Pt), generator power (Pg) and reflected power (Pref).

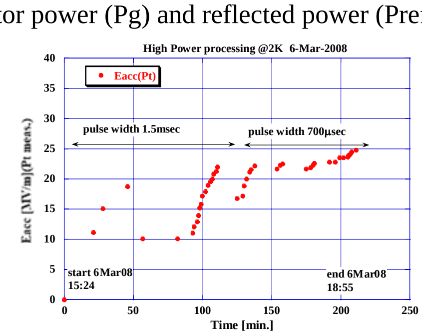

Figure 3: Processing of cavity

At the temperature of 2 K, the processing of cavity was performed. Figure 2 shows the pulse-shapes of Pt, Pg and Pref at 18 MV/m, where Pref is the reflected power at the coupler. The gradient of 22 MV/m with the pulse-width of 1.5 m sec at the repetition rate of 5 pps was achieved. The pulse-width was reduced to 700 μ sec and the gradient reached 25 MV/m as shown in Figure 3. The onset of X-ray was 10 MV/m but the X-ray started decreasing from 12 MV/m. Very little X-ray was observed above 20 MV/m and the gradient was limited by thermal breakdown. Heat-loss increased from the gradient of 12 MV/m and a steep drop of Q_0 was observed.

MEASUREMENT OF PHASE ROTATION

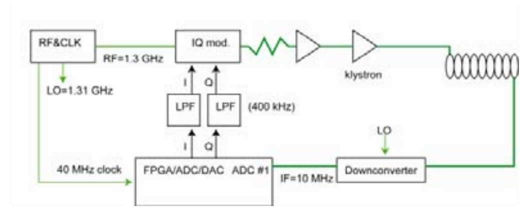

Figure 4: Diagram of I-Q measurement system, klystron, and cavity.

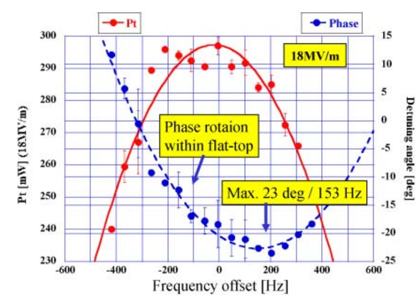

Figure 5: Measurements of amplitude and phase of Pt within flat-top with changing the frequency of input RF.

Figure 4 shows the diagram of the measurement system of RF amplitude and phase. The transmitted power: Pt was fed to the ADC and the data of I-Q measurement were taken in a computer [5]. Independent of this system, the phase difference between Pg and Pt was observed by using a mixer to cross-check the RF phase rotation of the cavity. This method was used to measure the microphonic noise. The measured amplitude of microphonic noise corresponds to the cavity phase rotation of +-0.5 degree which is equivalent to the detuning of +-3 Hz.

The amplitude and phase of Pt were measured by the I-Q measurement system with changing the frequency of RF signal fed to the klystron by a step of 50 Hz. The results are shown in Figure 5, where the detuning is the change of phase within the flat-top of Pt. The maximum phase rotation at the gradient of 18 MV/m was 23 degree which corresponds to the detuning of 153 Hz.

COMPENSATION OF LORENTZ FORCE DETUNING

Phase rotation caused by the Lorentz Force Detuning (LZD) was tried to be compensated by the ball-screw frequency tuner [6] which is designed to work in the combination of slow motor and fast piezo actuator.

Figure 6 (left-had side) shows driving signal for the piezo actuator with the two cycles of sine-wave. Figure 6 (right-had side) shows the phase rotations with and without piezo tuning. We found that only piezo tuning with one-cycle sine-wave is enough to compensate LFD at the gradient of 20 MV/m. In order to estimate the phase stability with fast tuning in 5 pps operation, we kept measuring the phase rotation with driving piezo actuator at 17 MV/m during 30 minutes. The mean value of phase rotation was 3.7 degree with the standard deviation of 1.9 degree without digital feed-back. The stability test was done also with applying digital feed-back at 18.6 MV/m. The deviations of amplitude and phase within flat-top were 0.05% (rms) and 0.02 degree (rms), respectively.

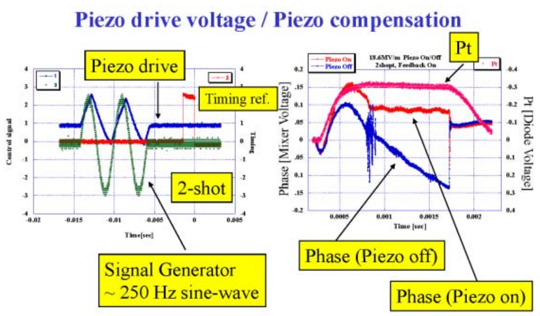

Figure 6: Compensation of LFD with piezo actuator.

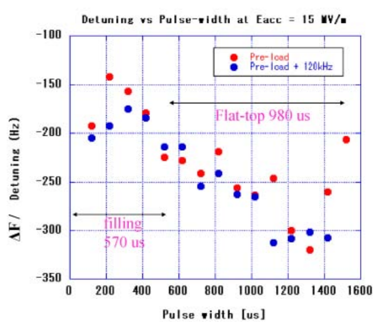

Figure 7: Detuning measurements by dΦ/dt method with changing the pulse-width from 100 μ sec to 1.5 m sec. Data denoted by blue dots were taken with applying higher tension to the cavity by the slow tuner than the data of red dots. The difference of tension corresponds to the detuning of 120 kHz.

LFD including both the filling and flat-top durations within each pulse can be estimated by dΦ/dt measurement method. In this method, dΦ/dt is measured just after the flat-top ends and Pt starts decaying, where Φ is the phase and t is the time. The measured dΦ/dt is equivalent to 2π times (LFD including filling and flat-top durations). If dΦ/dt is measured with changing the pulse-width, the development of LFD within each pulse can be estimated. This measurement was done at the gradient of 15 MV/m and the result is shown in Figure 7.

LFD was measured by dΦ/dt method with fixing the pulse-width at 1.5 m sec and changing the gradient from 11 to 15 MV/m. The result is shown in Figure 8. Data were fitted with a linear function and κ = 1.1 [Hz/(MV/m)^2] was obtained.

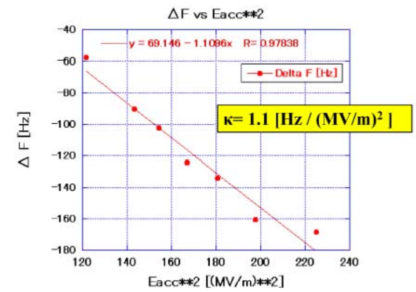

Figure 8: LFD measurements by dΦ/dt method with the pulse-width of 1.5 m sec at various gradients. κ = 1.1 [Hz/(MV/m)^2] was obtained from data fitting.

SUMMARY

The first cooling-down test of one LL 9-cell cavity was successfully done. The Q_L of cavity was measured by several methods with good agreement : Q_L = 1.7E6. Microphonic noise was measured to be +-0.5 degree / +-3Hz. The gradient of 22 MV/m with the pulse-width of 1.5 m sec at repetition rate of 5 pps was achieved. Very little X-ray was observed above 20 MV/m and the limitation was thermal breakdown. The maximum Lorentz Force Detuning (LFD) within the flat-top of pulse at 18 MV/m was 23 degree / 153 Hz. When LFD was compensated by piezo actuator, the standard deviation of phase within flat-top was 1.9 degree at 17 MV/m without digital feed-back. The deviations of amplitude and phase with digital feed-back were 0.05% (rms) and 0.02 degree (rms), respectively. LFD inluding filling and flat-top durations was measured by dΦ/dt method at various gradients and κ = 1.1 [Hz/(MV/m)^2] was obtained.

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