CRYOMODULE TESTS OF THE STF BASELINE 9-CELL CAVITIES AT KEK

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Abstract

A cryomodule including one of four TESLA-like cavities was assembled, and the cryomodule was installed in the tunnel for the initial test, called the STF Phase-0.5. The first cool-down of the cryomodule and high power tests of the cavity had been carried. The maximum accelerating gradient (Eacc,max) of 19.3 MV/m was achieved in a pulse width of 1.5 msec and a repetition of 5 Hz, (23.4 MV/m in a shorter pulse width of 0.6 msec). Compensation of Lorentz force detuning at 18 MV/m was successfully demonstrated by using a piezo tuner.

INTRODUCTION

Construction of STF (Superconducting RF Test Facility) is being carried out at KEK for the future ILC (International Linear Collider) project, [1]. The main purpose of the STF is to develop cryomodules including eight high gradient cavities, which can be stably operated at an average accelerating gradient of 31.5 MV/m. The STF-Baseline superconducting cavity system, which includes four TESLA-like 9-cell cavities, input couplers and frequency tuners, was designed and fabricated. The component tests of the cavities and the couplers were carried out in order to qualify their performances, [2, 3]. In the first step of the STF, a cryomodule including one of four TESLA-like cavities was assembled for the STF Phase-0.5. The first cool-down test of the cryomodule was started in October, 2007, and the high power test of the cavity at 2 K was successfully carried out in November, 2007. The cryomodule tests of four cavities have already started in May, 2008, as the STF Phase-1.0.

In this paper, the results of low power rf tests and high power rf tests in the STF Phase-0.5 are described.

SC CAVITY SYSTEM

The STF-Baseline superconducting cavity system is mainly consists of four TESLA-like STF-Baseline 9-cell cavities, input couplers and frequency tuning systems. In the STF-Baseline cavities shown in Figure 1, several modifications of the structure were made in order to improve the stiffness in a TESLA cavity; thick Ti endplates were used for suppressing a cell-shrink in the axial direction due to Lorentz force. The input couplers have a simple structure with no variable coupling, and Tristan-type coaxial ceramics disks are used for the cold and warm rf windows. The frequency tuning system consists of a slide-jack tuner for a mechanical slow tuning and a piezo tuner for an electrical fast tuning, as shown in Figure 2.

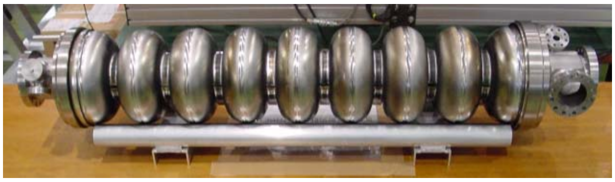

Figure 1: A TESLA-like STF-Baseline 9-cell cavity, [2].

Figure 2: Left is two pairs of cold and warm couplers, [3]. Right is a frequency tuner system, [4].

CRYOMODULE ASSEMBLY

After the cavity performance was qualified in the vertical tests, the four cavities were transported to a company, and they were covered with a magnetic shield and a titanium jacket for filling liquid helium. One dressed cavity (#3 Cavity) for the STF Phase-0.5 was assembled with an input coupler and a gate-valve in a class-10 clean room, as shown Figure 3. The cavity equipped with the tuner system was mounted under the gas-return pipe. The completed cryomodule containing one cavity was installed in the STF tunnel, as shown in a picture of the right side.

Figure 3: Attachment of an input coupler in a clean room, (Left, top). An assembled cavity mounted under the 2 K gas-return pipe, (Left, bottom). A 6-m long cryomodule installed in the STF tunnel, (Right).

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LOW POWER RF TESTS

The cryomodule had been cooled-down from room temperature to 4.2 K in about one week. Then, the cavity temperature was reduced to 2 K by pumping-down of liquid helium from 100 kPa to 3 kPa. First of all, low power rf measurements like tuner characteristics were carried out at 2 K. As shown in Figure 4, the dynamic range of the frequency change by the slide-jack tuner was about 500 kHz, and the frequency sensitivity was 280 kHz/mm. The frequency change by the piezo tuner was about 250 Hz in a constant applied voltage of +500 V, but a hysteresis stroke caused by some mechanical friction was observed. Pulse response driven by the piezo tuner was measured, as shown in Figure 5. The delay time from the input pulse signal to the observed phase difference ($\Delta\phi$) was about 0.7 msec, and the detuning angle and the detuning frequency was $+15^{o}$ and +150 Hz, (Q_L=1.2 E+6), respectively. The phase oscillation after the drive pulse was observed, but the oscillation was sufficiently damped before the next pulse in the 5 Hz operation.

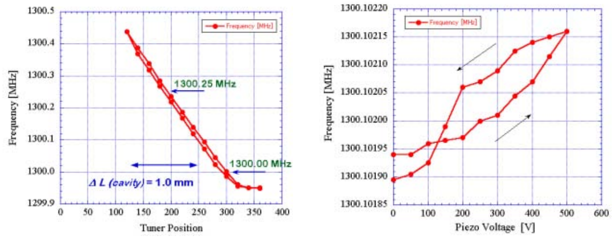

Figure 4: Frequency change by a slide-jack tuner, (Left). Hysteresis stroke of a piezo tuner with the constant applied voltage between 0 and +500 V (Right).

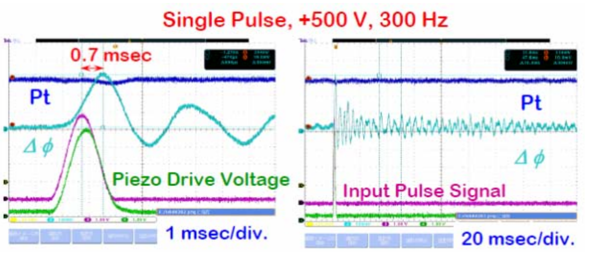

Figure 5: Pulse response signals driven by a piezo tuner with a single pulse of 300 Hz and +500 V: The dark blue line (Pt) is a transmitted rf power signal through the cavity in a cw operation at a low Eacc of 0.3 MV/m. The light blue line ($\Delta\phi$) is a phase difference between an input rf power and a transmitted rf power. The pink line is a pulse signal by a pulse generator. The green line is a piezo drive voltage by an amplifier. Left is a short time scale. Right is a long time scale.

HIGH POWER RF TESTS

Rf processing of the input coupler at room temperature before the cool-down was carried out up to 250 kW under the total reflection condition. The initial rf processing results of the cavity at 2 K is shown in Figure 6. The x-ray radiation due to multipacting around HOM couplers was observed at higher than 4 MV/m, but the x-ray activity was disappeared below 15 MV/m by rf processing. Finally, the Eacc,max in a 1.5 msec operation was limited at 19.3 MV/m by quench.

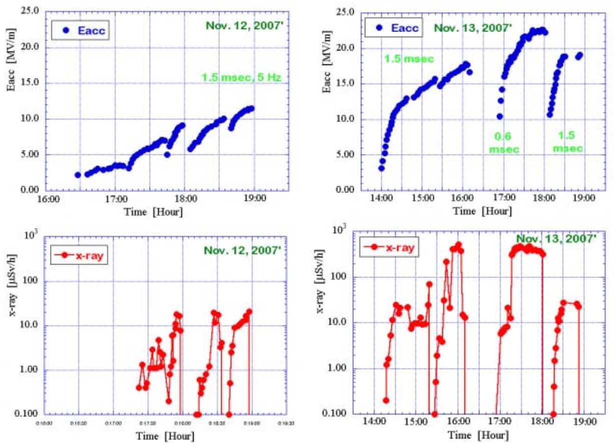

Figure 6: Time evolution of the accelerating gradient (top) and the x-ray radiation level (bottom) during the initial rf processing for two days.

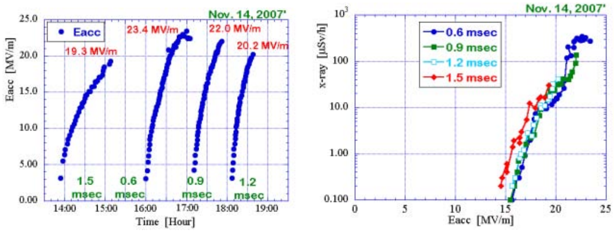

Figure 7: Achieved Eacc,max in the 5 Hz operation with the different pulse width of 0.6, 0.9, 1.2 and 1.5 msec, (Left). The correlation between Eacc and x-ray radiation level in the different pulse width, (Right)

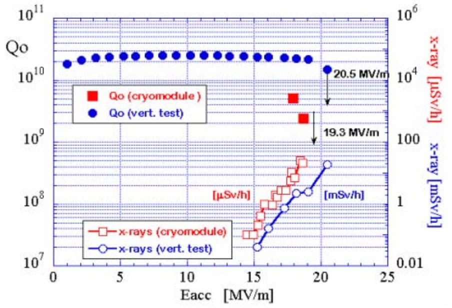

Figure 8: Qo vs. Eacc plots and x-ray radiation level as a function of Eacc in the cryomodule test (Red), and the results in the vertical test (Blue).

The achieved Eacc,max in the different pulsed operation was shown in Figure 7. The Eacc,max in the 0.6 msec operation was 23.4 MV/m, and the attained Eacc,max gradually decreased with a longer pulse width. Therefore, it is considered that the achievable Eacc,max is limited by an total amount of the heat loss at the hot spot. One potential cause is the heat loss due to impact electrons by field emission from the observation of x-ray radiation, as seen in the right in Figure 7.

Unloaded Q value (Qo) was measured at the Eacc of 18.7 and 17.9 MV/m by a flow rate of the evaporated helium gas [5], and the obtained Qo values are plotted in Figure 8, together with the vertical test results. The achieved Eacc,max was almost a similar level in both tests, but the drop of the Qo values in the cryomodule tests is supposed to be caused by field emitted electrons.

Figure 9 shows a typical pulse signals in a stable operation at 18 MV/m. The input rf power of 140 kW is reduced to 100 kW (70%) after 0.5 msec by a step pulse to maintain the flat Eacc. The phase difference ($\Delta\phi$) between an input rf power and an transmitted rf power shows the cavity detuning angle due to Lorentz force, and the observed $\Delta\phi$ is -15° in the end of the flat-top at 18 MV/m.

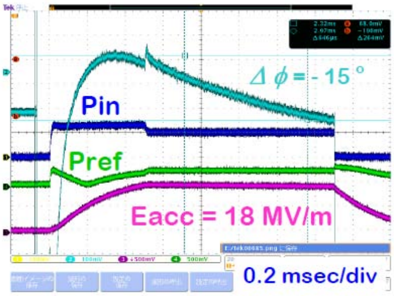

Figure 9: Typical pulse signals observed at the Eacc of 18 MV/m in a 1.5 msec and 5 Hz operation: The light blue line is a phase difference ($\Delta\phi$) between an input rf power and an transmitted rf power. The dark blue line is an input rf power (Pin), the green line is a reflected rf power (Pref), and the pink line is an accelerating gradient (Eacc).

COMPENSATION OF LORENTZ FORCE DETUNING

Pre-Detuning

A resonant frequency of a cavity at the flat-top gradually lowers due to Lorentz force detuning, as shown by $\Delta\phi$ in Figure 9. Therefore, setting a resonant frequency of a cavity higher than a drive frequency of an rf power source in advance (so-called pre-detuning or offset-detuning) is effective to suppress Lorentz detuning. Figure 10 shows a comparison between without pre-detuning and with pre-detuning. As seen in the $\Delta\phi$ signal, the detuning angle of -15° at 18 MV/m was suppressed to -6° by pre-detuning of +200 Hz.

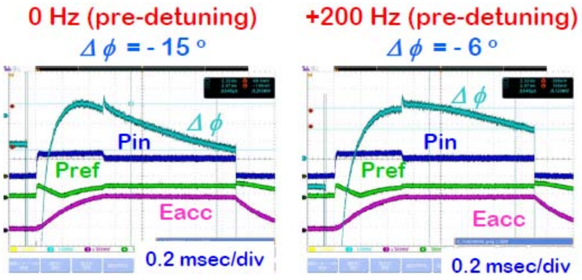

Figure 10: Effect of the pre-detuning for suppressing the Lorentz detuning: Comparison of the pulse signals at the Eacc of 18 MV/m without pre-detuning (Left) and with pre-detuning of +200 Hz (Right).

Compensation by a Piezo Tuner

Optimization of timing, frequency, amplitude and waveform of the drive pulse signal to a piezo tuner is important for an effective compensation of Lorentz detuning. A high voltage type piezo element (maximum +1000 V) is used for the piezo tuner. The maximum load of 5 kN and the stroke at a low temperature of about 4 μm are required. One example of a successful compensation of Lorentz detuning by the piezo tuner is shown in Figure 11. In this case, the starting time of the drive pulse is 0.7 msec before the rf pulse, and the frequency and the amplitude are 300 Hz and +500 V. Since reducing an applied voltage to a piezo is advantageous for a long life operation, compensation by a combination of the pre-detuning and the piezo tuner is an efficient method.

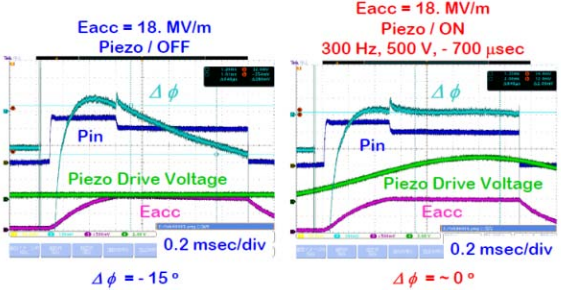

Figure 11: Successful compensation of the Lorentz detuning by the piezo tuner: Comparison of the pulse signals between with no piezo drive pulse (Left) and with a piezo drive pulse of 300 Hz and +500 V (Right).

SUMMARY

- Overall SC system consisting of the STF-Baseline cavity, the input coupler and the frequency tuner had worked well without any big troubles.
- Stable pulsed operation at 19 MV/m was confirmed in the high power tests, and no severe degradation of the cavity performance was observed in comparison with the result in the vertical tests.
- Compensation of Lorentz force detuning at 18 MV/m was successfully demonstrated by using a piezo tuner.

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