OBSERVATION AND NUMERICAL CALCULATION OF LORENTZ-DETUNING FOR THE CRYOMODULE TEST OF STF BASELINE CAVITIES AT KEK-STF

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Abstract

The Cryomodule test was finished at KEK-STF (Superconducting rf Test Facility) on December/2008. The four 9-cell cavities were installed into it and measured around 2K for totally a few months. One cavity achieved around 32MV/m with the feed-back and the others around 20MV/m. During the high power test with a klystron, the Lorenz detuning was observed and measured for these cavities. Generally, the Lorentz detuning is almost compensated by setting the offset of the cavity frequency in advance (pre-detuning) and driving the Piezo actuator with an optimum condition. The driving condition for Piezo was obtained, which controlled the detuning frequency of the cavity within ±30Hz.

INTRODUCTION

The Cryomodule test, which four 9-cell cavities were used, started at KEK-STF from May/2008. One of these cavities achieved above 30MV/m and operated stably for several hours. The overview of the Cryomodule test is described in the paper [1]. The cold test was successful and many data for the various tests were obtained. The contents of these tests are the high power test, the drive test for the motor tuner and Piezo tuner, the measurement of Q_L, Q_t and Q_{HOM}, the Q_0 measurement, the measurement of the static loss, the observation of the Lorentz detuning around 30MV/m and the compensation of the Lorentz detuning using Piezo at the same gradient.

The cavity is generally deformed, when it is operated at the high gradient. This deformation leads to the detuning of the cavity and eventually the field degradation. It is crucial to compensate this effect by an artificial method in the pulsed operation at the high gradient like ILC (International Linear Collider). The feed-forward (F.F.) method by Piezo drive and the feed-back (F.B.) method by LLRF (Low Level RF) control are generally used for the compensation [2]. The Cryomodule test at STF was completely successful for both methods.

A physics picture was devised to offer the physics explanation for the observational results. It is called “Two Modes Model”, because it is supposed that the two mechanical modes mainly contribute to the Lorentz detuning. The results of the numerical calculation using this model are almost consistent with the observational ones.

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In this paper, the observation and compensation results of the Lorentz detuning in the Cryomodule test are described in detail with the results of the numerical calculation by “Two Modes Model”.

MECHANISM OF SLIDE-JACK TUNER

Figure 1 shows the tuner used for the Cryomodule test at STF, which is called Slide-Jack tuner. It is attached at the side of the input coupler on the helium jacket. When the Slide-Jack moves along the stud bolt vertically, the free end plate moves horizontally and the bellow expands. Therefore, the cavity expands and the frequency is changed. For the fine tuning of the frequency, Piezo actuator is used. The Slide-Jack tuner typically changes the frequency by several hundred kHz and Piezo tuner does by several hundred Hz at maximum.

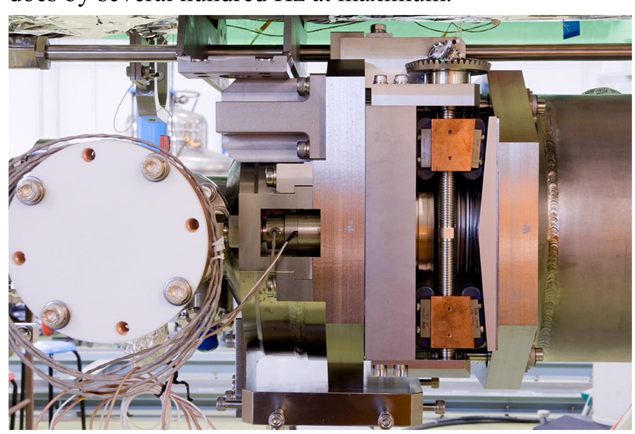

Figure 1: Slide-Jack tuner at STF Cryomodule.

OBSERVATION AND COMPENSATION OF LORENTZ DETUNING

Observation of Lorentz Detuning

Figure 2 shows the observational results of the Lorentz detuning during the high power test. The cavity is largely deformed as shown in the left figure, when the feed-back control and Piezo do not work and the pre-detuning is not set at all. The Lorenz detuning is almost compensated in the right figure, when F.B. control works and the pre-detuning is appropriately set. However, the klystron output is gradually increased during the flat-top of the pulse in this case, because of F.B. control. This means that the extra power and the higher margin for klystron are necessary.

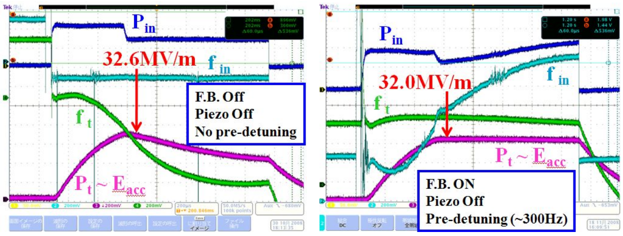

Figure 2: Observation of Lorentz detuning during the high power test without F.B. and the pre-detuning (left), and with them (right). Blue shows the klystron output, green shows the cavity phase and purple shows the cavity field.

Evaluation of Lorentz Detuning

As the evaluation method of the Lorentz detuning, a pulse shortening method is usually used [3]. It is possible to obtain the Lorentz detuning by gradually shortening the pulse width. Figure 3 shows the examples of the pulse shortening for two cases of 1500 and 700µsec. The loaded Q and the detuning frequency are obtained from the behaviour of the pulse end for the logarithmic cavity field and the cavity phase. Figure 4 shows the result of these two parameters obtained by this method. The total detuning frequency from the beginning to the end of the pulse is about 700Hz in this case without F.B. and Piezo.

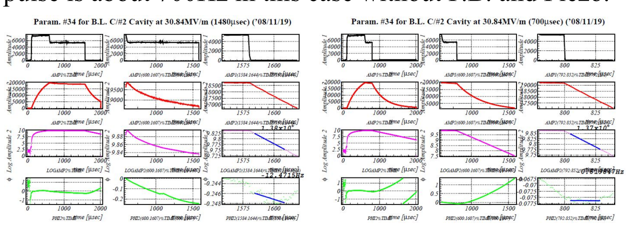

Figure 3: Examples of the pulse shortening method. Left shows the full width (1500µsec) and right shows 700µsec. Klystron output, cavity field, logarithmic cavity field and cavity phase are shown from top to bottom. The cases of full pulse, flat-top and pulse end are shown from left to right.

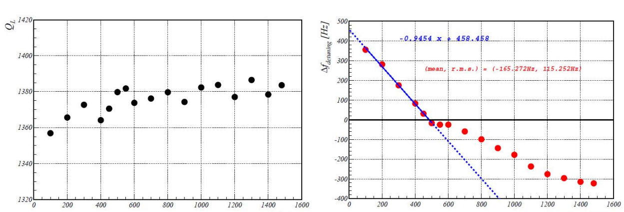

Figure 4: Result of the Loaded Q (left) and the detuning frequency (right) by the pulse shortening method. F.B. and Piezo are not used in this case.

Compensation of Lorentz Detuning Using Piezo

Piezo actuator is used as F.F. control to compensate the Lorentz detuning at KEK-STF. It is possible to do that, if Piezo is driven with some optimum conditions before the arrival of RF pulse. Many parameters of Piezo drive were tried to search those conditions without F.B. These parameters are as follows:

- The initial offset of the cavity frequency (f_{offset})
- The driving voltage of Piezo (V_{piezo})
- The driving frequency of Piezo (f_{piezo})
- The time difference between RF pulse and Piezo action (t_{delay})

Figure 5 shows the results of the compensation for the Lorenz detuning using Piezo around 30MV/m. Klystron output is not changed during the flat-top for F.F. method. Figure 6 shows the two different examples of Piezo compensation measured by the pulse shortening method. From many results of Piezo compensation, the optimum condition of Piezo drive is obtained, which controls the detuning frequency of the cavity within ±30Hz. Figure 7 shows the optimum region for the above parameters [4].

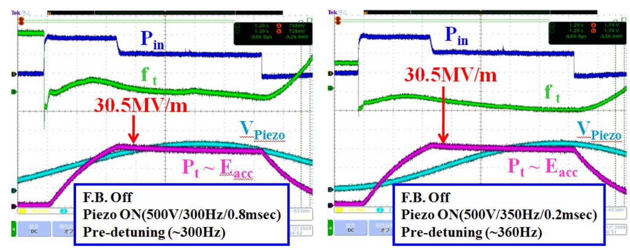

Figure 5: Compensation of the Lorentz detuning by Piezo. Light blue shows the drive pulse of Piezo.

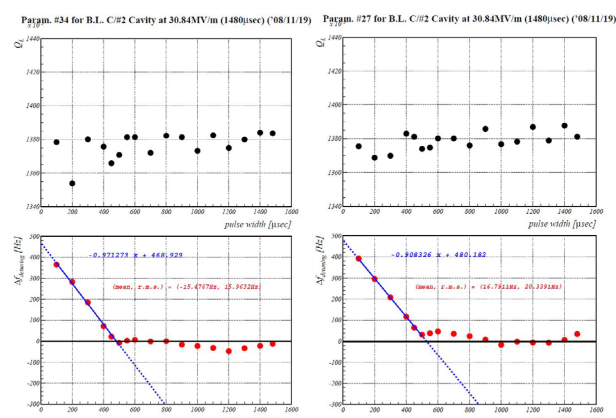

Figure 6: Examples of Piezo compensation measured by the pulse shortening method around 30MV/m.

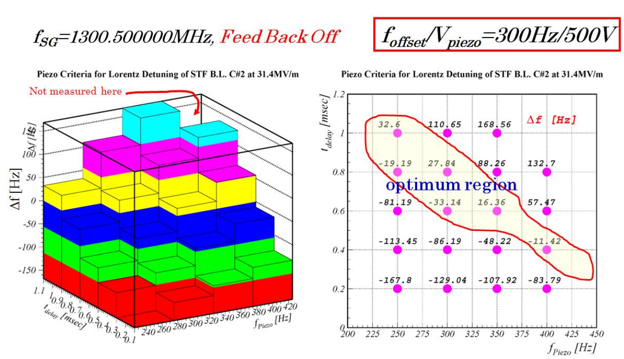

Figure 7: Optimum region of Piezo drive for the compensation of the Lorentz detuning. The vertical axis in the left is the detuning frequency. The numerical values in the right are the detuning frequency.

Pulse Stability Test

The pulse stability test was carried out for a long time around 30MV/m. The operation by Piezo compensation was stable for several hours. Figure 8 shows the example of the pulse stability for 16 minutes. The r.m.s. of the detuning frequency was about 5Hz and the peak-to-peak of the cavity field at the flat-top was below 0.1%.

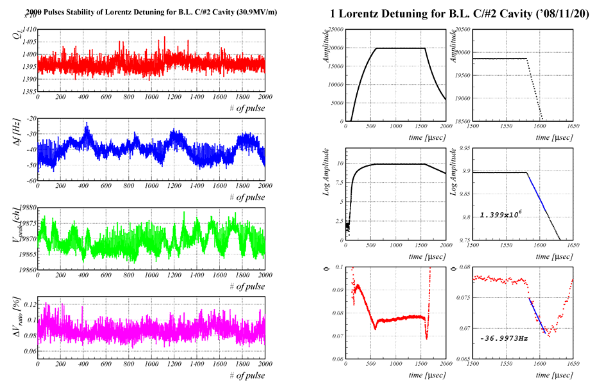

Figure 8: Result of the pulse stability test around 30MV/m. Left shows the time trend and right shows the status of one pulse.

NUMERICAL CALCULATION USING "TWO MODES MODEL"

The "Two Modes Model" was devised to offer the physics explanation for the observational results of the Lorentz detuning. This model is supposed that two mechanical modes mainly contribute to that. One is the fast mode, which frequency is several kHz. The other is the slow mode, which frequency is several hundred Hz. It is possible to reproduce the real data by combining these two modes properly. The numerical calculation was performed using the cavity voltage equation from Slater's textbook [5]. Figure 9 shows the comparison of the results for the detuning angle between the observation around 30MV/m and the calculation. They are almost consistent each other for two different pre-detuning. Therefore, the "Two Modes Model" is valid as the explanation of the Lorentz detuning. It is surprising that the "Two Modes Model" reproduces the observational result, in spite of the presence of the infinite mechanical mode.

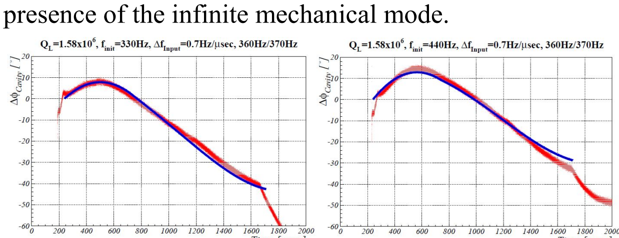

Figure 9: Comparison of the results between the observation (red) and the numerical calculation (blue).

SUMMARY & FUTURE PLAN

The Cryomodule test at KEK-STF was completely successful and the high power operation was stable. One cavity achieved above 30MV/m and many observational results for the Lorentz detuning were obtained. The compensation of the Lorentz detuning was successful for the both methods of F.B. and F.F. The optimum condition for Piezo drive was obtained, which controls the detuning frequency of the cavity within ±30Hz. The "Two Modes Model" well reproduces the observational results.

From 2010, S1-Global project will start at KEK-STF. The four new cavities will experience the various tests. The LLRF system will be more useful and more effective for these tests.

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REFERENCES

[1] E. Kako et al., "Cryomodule Tests of Four Tesla-like Cavities in the STF Phase-1.0 for ILC", PAC'09, Vancouver, Canada, (2009) in these proceedings, TU3RAI04.

[2] S. Michizono, et al., "Vector-Sum Control of Superconducting rf Cavities at STF", PAC'09, Vancouver, Canada, (2009) in these proceedings, WE5PFP083.

[3] S. Simrock, et al., "Lorentz Force Compensation of Pulsed SRF Cavities", LINAC 2002, Gyeongju, Korea, (2002), p.554.

[4] Y. Yamamoto, et al., TILC09, Tsukuba, Japan, (2009). (URL:http://ilcagenda.linearcollider.org/conferenceOtherViews.py?view=standard&confId=3154)

[5] J.C. Slater, "Microwave Electronics", Rev. Mod. Phys. 18, 441-512, (1946).