EXPERIMENTAL RESULT OF LORENTZ DETUNING IN STF PHASE-1 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 (MHI#1-#4) were installed into it and measured around 2K for totally a few months. MHI#2 cavity achieved around 32 MV/m (29 MV/m at vertical test) with the feed-back and the others around 20 MV/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 optimum driving condition for the Piezo actuator was obtained, which controlled the detuning frequency of the cavity within ±30Hz. The MHI#2 cavity was stably operated around 30 MV/m with the Piezo compensation for several hours. During this operation, the r.m.s. of the detuning frequency was about 5Hz and the peak-to-peak of the gradient at the flat-top was below 0.1%.

INTROCUDTION

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, 2]. 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 the 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 the 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 the Piezo drive and the feed-back (F.B.) method by LLRF (Low Level RF) control are generally used for the compensation [3]. The cryomodule test at STF was completely successful for both methods.

MECHANISM OF SLIDE-JACK TUNER

Figure 1 shows the mechanical tuner used for the cryomodule test at STF Phase-1, 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 movable end plate moves horizontally and the bellow expands. Therefore, the cavity expands and the frequency is increased. For the fine tuning of the frequency, the Piezo actuator is used. The Slide-Jack tuner typically changes the frequency by several hundred kHz and the Piezo tuner does by several hundred Hz at maximum.

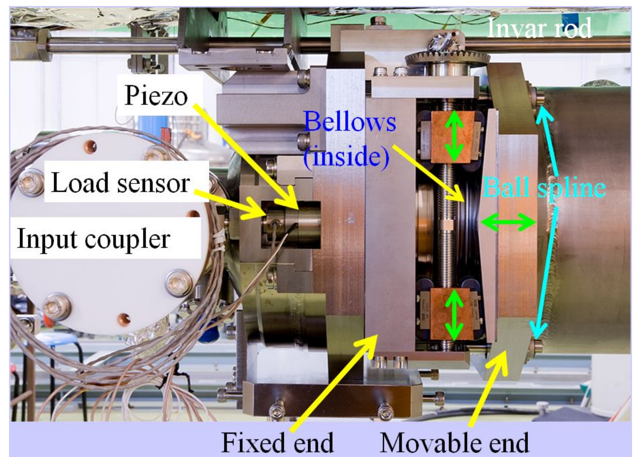

Figure 1: Slide-Jack tuner at STF.

PIEZO ACTUATOR AND LOAD SENSOR

Figure 2 shows the Piezo actuator (top) and the load sensor (bottom). There are two types for them. For the Piezo actuator, one is the 150V type and the other is the 1000V type. The size is different between them. The deformation range is also different. On the other hand, there are two types for the load sensor. One is the Aluminum and the other is the Beryllium type. However, they did not work well at 2K. Table 1 shows the specification of them. Actually, the operation range of the Piezo actuator is narrower compared to the design to avoid the breakdown.

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Figure 2: Two types of Piezo actuator and load sensor

Table 1: Specification of Piezo actuator and load sensor

Cavity	MHI#3	MHI#4	MHI#2	MHI#1
Piezo type	150V	150V	1000V	150V
Operation range	0~100V	0~100V	0~500V	0~100V
Load sensor type	Aluminum	Alminum	Beryllium	Beryllium

OBSERVATION AND COMPENSATION OF LORENTZ DETUNING

Observation of Lorentz Detuning

Figure 3 shows the observational results of the Lorentz detuning during the high power test. The cavity is largely deformed as shown in the top figure, when the feed-back control and the Piezo does not work and the pre-detuning is not set at all. The Lorenz detuning is almost compensated in the bottom figure, when the F.B. control works, the pre-detuning is appropriately set and the Piezo actuator does not work. However, the klystron output is gradually increased during the flat-top of the pulse in this case, because of the F.B. control. This means that the extra power and the higher margin for klystron are necessary. For the effective operation, the Piezo is necessary as the feed-forward control.

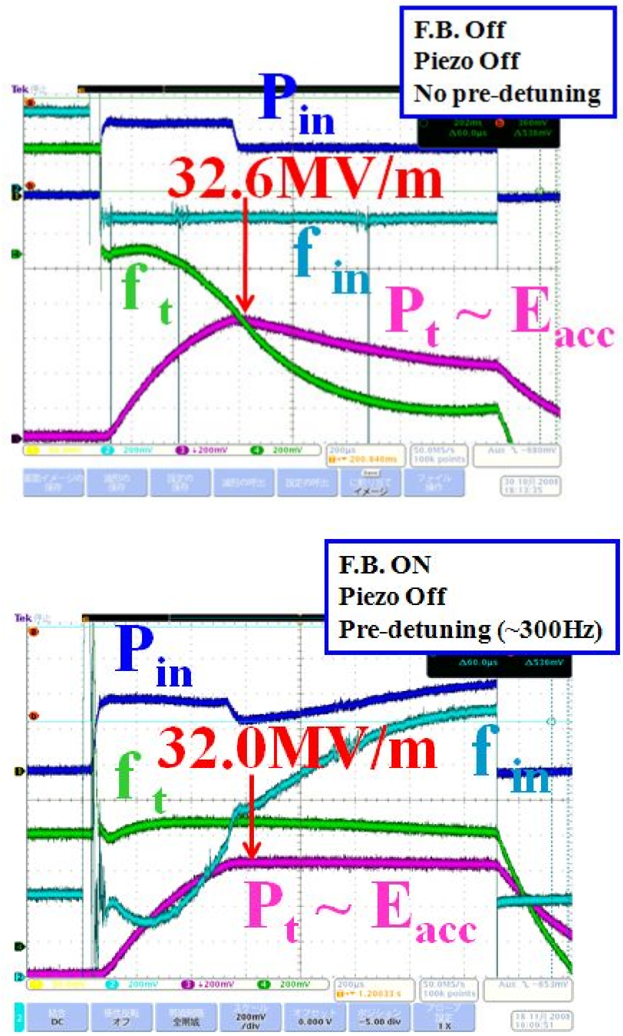

Figure 3: Example of the Lorentz detuning (top) and the compensation by F.B. control (bottom).

Evaluation of Lorentz Detuning

As the evaluation method of the Lorentz detuning, a pulse shortening method is usually used [4]. It is possible to obtain the Lorentz detuning by gradually shortening the pulse width. Figure 4 shows the example of the observed pulse data. The loaded Q (Q_L) is estimated from $Log_{10}E$ and the detuning frequency (Δf) is estimated from $d\varphi/dt$ at the pulse end. Figure 5-7 show the examples of the pulse shortening for three cases of 400, 800 and 1480μsec. Figure 8 shows the result of the detuning frequency obtained by this method. The total detuning frequency during the flat-top of the pulse is about 370Hz in this case with the F.B. and without the Piezo.

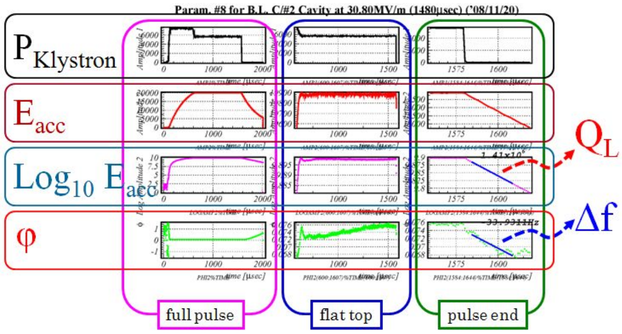

Figure 4: Example of the observed pulse data.

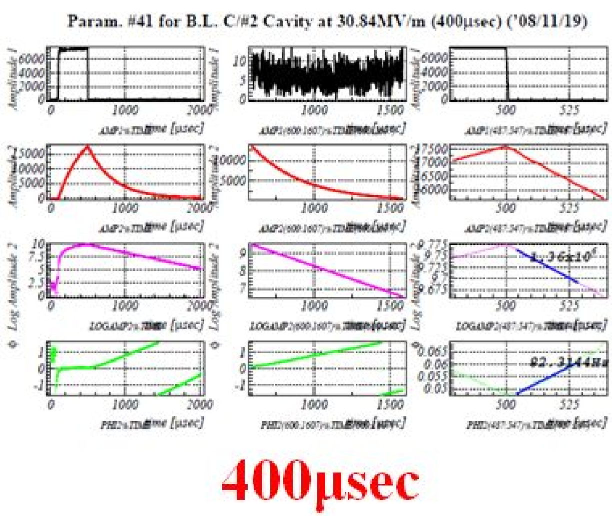

Figure 5: Pulse shortening at the 400μsec of the width.

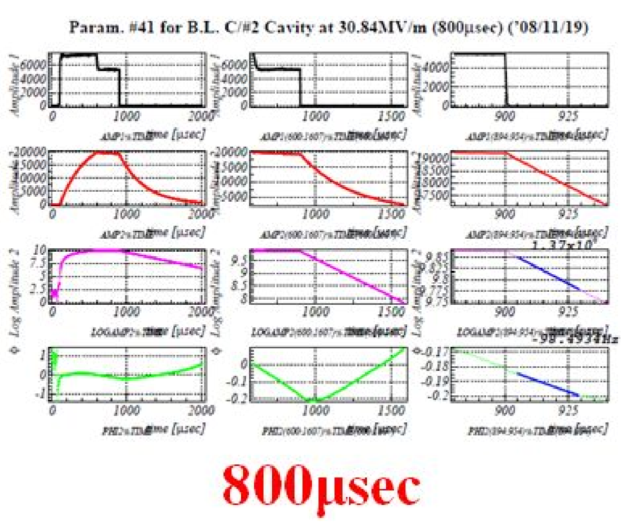

Figure 6: Pulse shortening at the 800μsec of the width.

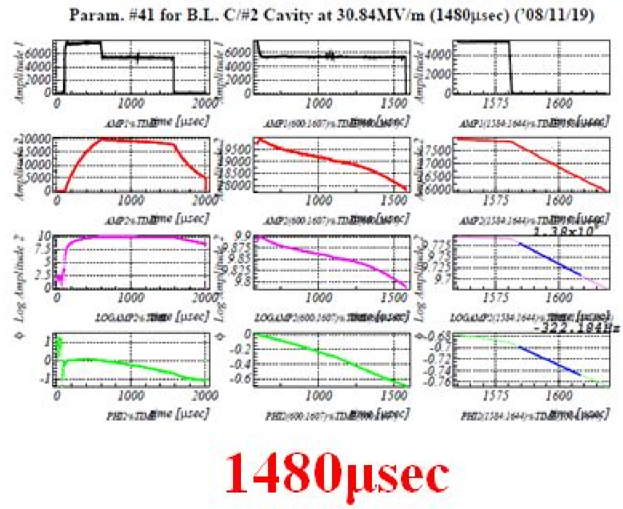

Figure 7: Pulse shortening at the 1480μsec of the width.

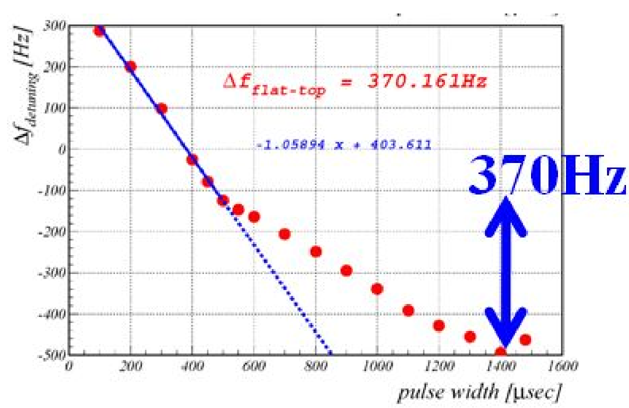

Figure 8: Example of the result by the pulse shortening.

Compensation of Lorentz Detuning using Piezo

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

- 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 9 shows the results of the compensation for the Lorenz detuning using the Piezo around 30MV/m. Klystron output is not changed during the flat-top for F.F. control. Figure 10 shows one example of the Piezo compensation measured by the pulse shortening method. From many results of the Piezo compensation (Figure 11), the optimum condition of the Piezo drive is obtained, which suppresses the detuning frequency of the cavity within ±30Hz at the flat-top of the pulse. Figure 12-13 show the optimum region for the above parameters [5].

From these plots, it is found that there is the comparatively wide region for the drive parameters of the Piezo.

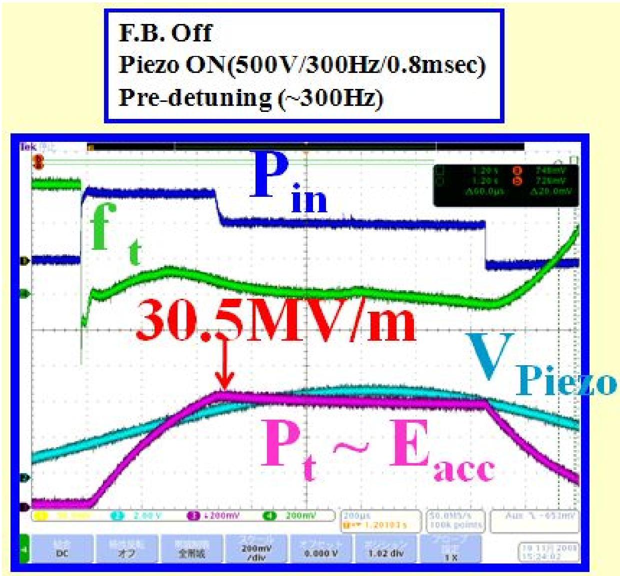

Figure 9: Example of the compensation by F.F. control.

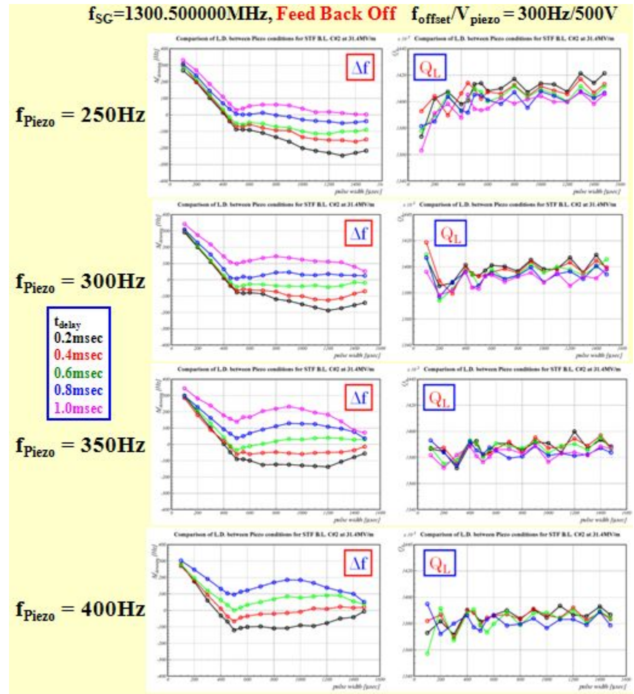

Figure 11: Examples of the Piezo compensation using many drive parameters.

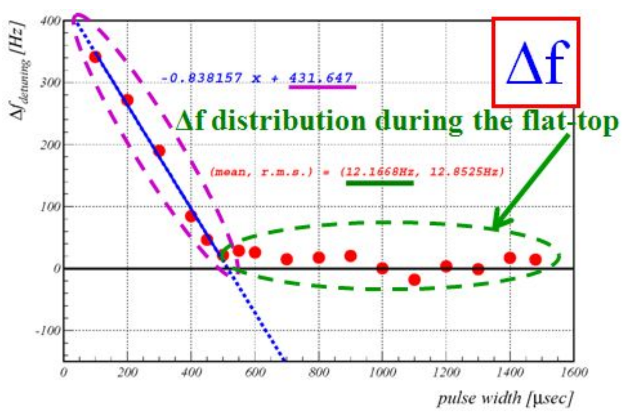

Figure 10: Result of the compensation using F.F. control by the pulse shortening.

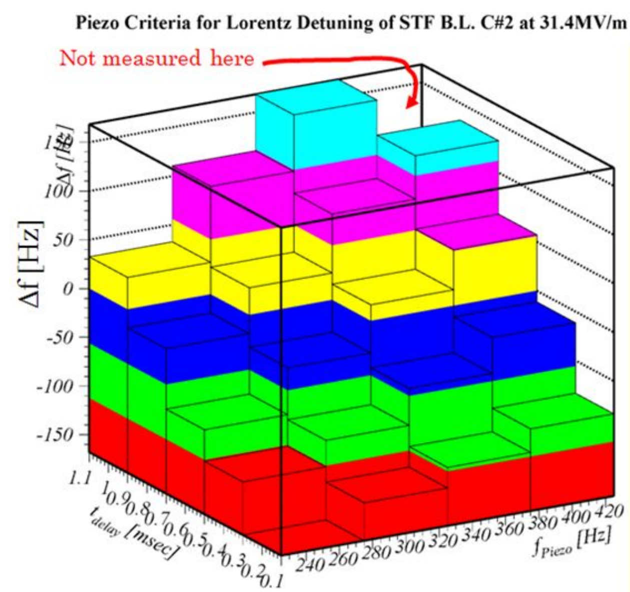

Figure 12: Example of the optimum condition for the Piezo drive around 30MV/m (3D plot).

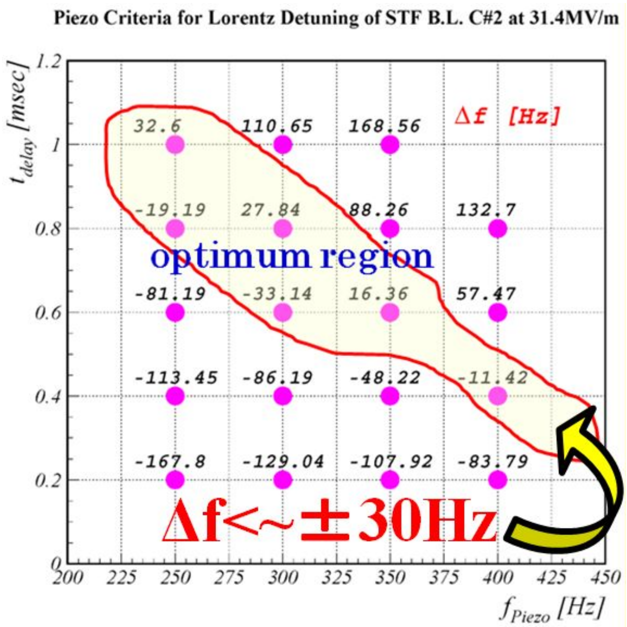

Figure 13: Example of the optimum condition for the Piezo drive around 30MV/m (2D plot).

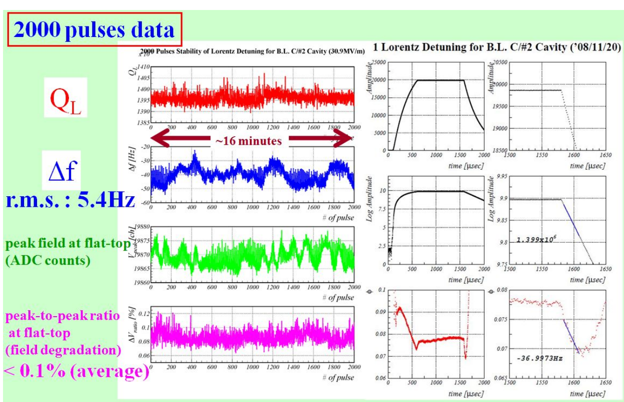

Figure 14: Example of the pulse stability test for the long term. The left figure shows the trend graph during the long term test. The right figure shows the example of one pulse.

Pulse Stability Test

The pulse stability test was carried out for a long term around 30MV/m. The operation with the compensation of the Lorentz detuning by the Piezo actuator was stable for several hours. Figure 14 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 <0.1%.it is necessary to do much longer term test in S1-Global project.

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 the F.B. and the F.F. The optimum condition for the Piezo drive was obtained, which controls the detuning frequency of the cavity within ±30Hz.

From 2010, S1-Global project will start at KEK-STF. The four new cavities delivered from KEK will experience the various tests. The other four cavities are delivered from DESY and FNAL. These cavities have different type of the mechanical tuner. KEK cavity has the Slide-Jack tuner. DESY cavity has a Saclay tuner. FNAL cavity has a Blade tuner. It is very important to compare the performance of these tuners in the S1-Global project. However, since the measurement time is very restricted, the LLRF system should be more useful and more effective for these tests.

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