BEAM INDUCED HOM ANALYSIS IN STF

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Abstract

11 km-long ILC Main Linacs of approximately 7400 superconducting (SC) 9-cell cavities have to accelerate beams with maintaining their low emittance to achieve high luminosity. Emittance growth occurs due to wakefield effect and dispersive effect. To avoid these effects, cavity alignment tolerance has to be kept less than 300 µm offset and 300 µrad tilt with respect to cryomodule axis [1]. Confirmation of their alignment quality is strongly required, however measurement of cavity alignment directly will be difficult because SC cavities are housed by helium jackets and installed in the cryomodules deep inside.

Cavity offset has been already measured by using beam induced 6π/9 mode (TE111-6, trapped mode) in the first dipole passband which has high impedance at FLASH in DESY [2 - 6]. To detect alignment of 9-cell SC cavities, we propose to use electrical centers of π/9 mode (TE111-1, trapped mode) in the first dipole passband and beam pipe modes. In 2012-2013, we took beam induced HOM data in STF (Superconducting rf Test Facility) accelerator. The detailed data analysis is introduced in this paper.

INTRODUCTION

Dipole modes are excited by off-axis beams and their amplitude are proportional to beam off-axis position [2]. When beam is swept in a transverse direction, a plot of their amplitude with respect to beam position shows a shape of V and a point where amplitude is on minimum is on their axis. By dividing two slope parts and making linear fit, we get a point where amplitude is on its minimum as a cross point of their linear fit functions. There are different polarized dipole modes whose frequencies are also different. A difference of these frequencies is less than 1 MHz. Directions of polarized modes usually different from the accelerator axis, such as horizontal X and vertical Y. A vertex of different polarized dipole modes' axis indicates an electrical center. Figure 1 shows conceptual diagram of detecting an electrical center. A diagonal beam sweep along with X and Y is necessary to determine an electrical center of tilted polarized modes.

To find cavity tilt and bending, we selected TE111–1 and beam pipe modes which are localized at both end-group of the SC cavity. From information of TE111-1 which has maximum radial electric field in the middle cell [7], we can get electrical center of middle cell. At beam pipes of both end of cavity, electrical center can be found by using beam pipe modes. Combinations of these electrical centers of localized modes give us cavity tilt and bending information.

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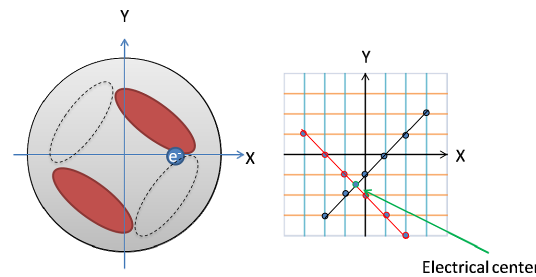

Figure 1: Conceptual diagram of detecting an electrical center.

EXPERIMENTAL SETUP

STF Accelerator

STF accelerator was operated in 2012-2013 for R&D of ILC [8, 9]. Electron beam extracted from the L-band photocathode RF Gun is accelerated to 40 MeV by two SC cavities [10]. Beam parameter used in this measurement is; 28 bunches with ~50 pC/bunch charge and 6.15 ns bunch spacing, 5 Hz repetition. The beam energy is; 4 MeV for the SC cavity input and 40 MeV for the output.

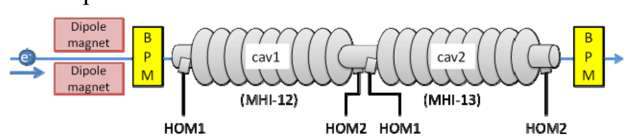

Figure 2: Simplified Layout of HOM detection setup. An electron beam comes in from the left through dipole magnets, beam position monitor (BPM), two SC cavities, and another BPM.

Figure 2 shows simplified layout of HOM detection setup. In this paper, we use upstream cavity only for the analysis. One cavity has two HOM couplers. Input coupler located in downstream end-group. BPMs located at upstream and downstream of a cryomodule. Two dipole magnets are located in front of the upstream BPM. One dipole magnet kicks beam X direction (horizontal axis), the other one kicks beam Y direction (vertical axis).

Data Taking

21-meter-long coaxial cables were connected to HOM couplers and an oscilloscope (Agilent Technologies DSO9404A). Two high pass filters (HPF) and a band pass filter (BPF) were used to detect TE111-1 and an IQ converter circuit was used to detect beam pipe modes. Correlated with taking HOM signals by the oscilloscope which 10 GSa/s 262 kpts, we took two BPM signals at the same beam passing during transverse beam sweep.

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Estimation of Beam Position

Base-line clipping circuit and averaging the signal over bunches were used in BPM electronics. Their signal charge integration gate width is 30 ns. From two BPM data, we estimated beam pass positions at the cavities. The beam position from these BPM was required a correction of non-linearity of the clipping circuits and non-linearity of calculation formula. By measuring circuit response curves and by simulating beam position response by HFSS code, we corrected beam position. We assume that beam orbit was linear between two BPMs.

DETECTION OF ELECTRICAL CENTERS

TE111-1

To examine the 1st dipole passband, we used two HPF (Mini-Circuits VHF-1500+) and a band pass filter (BPF) which pass only from 1.590 to 1.802 GHz. The different polarized modes were labelled as (a) and (b) in frequency order. A frequency of TE111-1(a) is 1.6087 GHz and one of TE111-1(b) is 1.6096 GHz. Both polarized modes coupled with HOM1 and HOM2. The electrical center of TE111-1 from HOM1 was (x, y) = (1179±725.6 μm, -705.9±186.0 μm) as shown in Fig.3, the electrical center of TE111-1 from HOM2 was (x, y) = (1189±363.4 μm, -682.0±82.63 μm) as shown in Fig.4. These electrical centers are in good agreement and consistent.

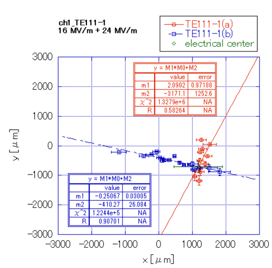

Figure 3: Electrical center of TE111-1 from HOM1.

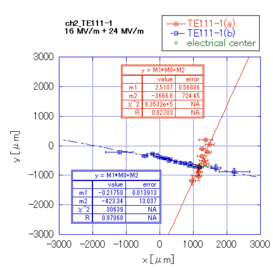

Figure 4: Electrical center of TE111-1 from HOM2.

TE111-6

To verify justification of our analysis, we also analyzed TE111-6, which used at FLASH in DESY. TE111-6(a) did not couple with HOM1 because relation between HOM coupler attachment angle and polarized angle was presumably wrong. Beam position at longitudinal center of cavity was used to estimate an electrical center.

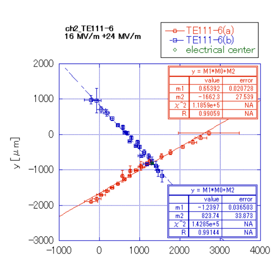

Figure 5: Electrical center of TE111-6.

The electrical center of TE111-6 as shown in Fig.5 was (x, y) = (1313±37.13 μm, -803.9±32.45 μm). The electrical center of TE111-6 was reasonably close to the electrical center of TE111-1.

Beam Pipe Modes

IQ converter as shown in Figure 6 was used to measure narrow frequency range with high sensitivity. We used it to measure beam pipe modes. Signal generator was set to 2.100 GHz, 10 dBm in power and the low pass filters (LPF) were set to 50 MHz. Frequency of beam pipe mode calculated for TDR-like TESLA 9-cell cavity is 2.288 GHz [7], however there was no signal in KEK cavities. Instead, V-shape response signal was found around 2.100 GHz. There were 4 peaks behaving like dipole mode for HOM1. For HOM2, there were 10 peaks behaving like dipole mode. In both case, we analyzed only two closed peaks which showed clear V-shape response. Assumed that these are beam pipe mode and have maximum amplitude at location of HOM coupler 1, at location of HOM coupler 2, we estimated beam passing position and got points where the amplitude is on their minimum.

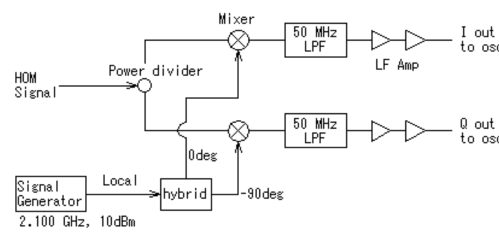

Figure 6: Schematic diagram of IQ Converter.

Figure 7 and Figure 8 show mapping plots which indicate that their electrical centers are (x, y) = (-1054±138.4 μm, -533.5±60.25 μm) and (x, y) = (311.1±126.2 μm, -582.9±52.91 μm) for HOM1 and HOM2 respectively. Analyzed peaks frequencies are summarized in Table 1. The different polarized modes were labelled as (a) and (b) in frequency order for HOM1, and as (c) and (d) for HOM2.

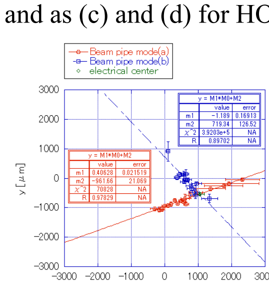

Figure 7:HOM1 mapping.

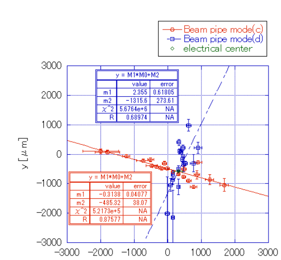

Figure 8:HOM2 mapping.

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Table 1: Observed Frequencies of the Beam Pipe Mode

Label		Δf [GHz] from 2.100 GHz
HOM1	Beam pipe mode (a)	0.0327
HOM1	Beam pipe mode (b)	0.0331
HOM2	Beam pipe mode (c)	0.0202
HOM2	Beam pipe mode (d)	0.0208

ALIGHNMENT DETECTION

The preliminary measured electrical center for TE111-1 and beam pipe modes are shown in Figure 9 as a function of cavity longitudinal position (z) and Table 2. The middle of cav1 is defined as z=0mm. The location of HOM1 is z=-565.3 mm, and for HOM2 z=565.3 mm. Axis of two BPM positions is a reference for these alignment detection. The positive direction of x axis is the side in which input coupler is inserted, and the positive direction of y axis is gravity direction.

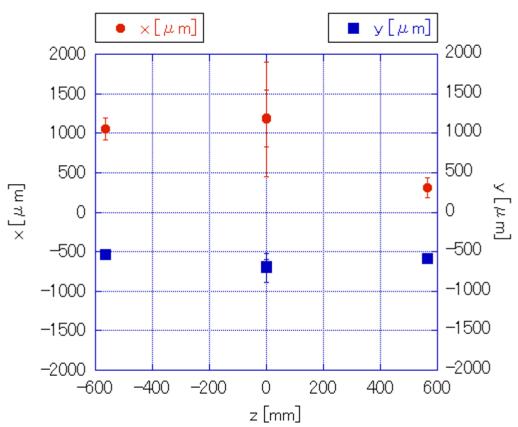

Figure 9: Preliminary alignment detection results, plotted along the cavity z-axis.

Table 2: The Electrical Centers

	Upstream beam pipe	Middle cell	Downstream beam pipe
z [mm]	-565.3	0	565.3
x [μm]	1054±138.4	1179±725.6 1189±363.4	311.1±126.2
y [μm]	-533.5±60.25	-705.9±186.0 -682.0±82.63	-582.9±52.91

The results are required to make deep consideration of electrical center shift from mechanical center by the HOM coupler antenna arrangement, and beam kicked effect by the couplers. To know detail alignment with respect to a cryomodule, we need to examine field distribution and simulation calculation about RF kick field. Consequently, the Figure 9 is a preliminary result without consideration of these effects.

RF KICK EFFECT

We measured beam induced HOM when RF power into SC cavities was turned off. This measurement was performed under detuned SC cavities so that the frequency of TE111-1(a) is changed to 1.6088 GHz and the frequency of TE111-1(b) is also changed to 1.6096 GHz. TE111-1(a) and (b) are coupled with both HOM couplers, and plots of amplitude of TE111-1(b) with respect to beam position shown a shape of V as shown in Figure 11, however those of TE111-1(a) didn't show a shape of V in beam sweep region as shown in Figure 10. Assumed that average of amplitudes of V shape bottom of TE111-1(b) is amplitude of V shape bottom of TE111-1(a), we estimate positions of V shape bottom.

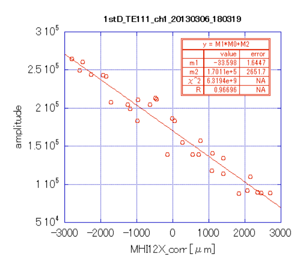

Figure 10: Beam position vs. amplitude of TE111-1(a).

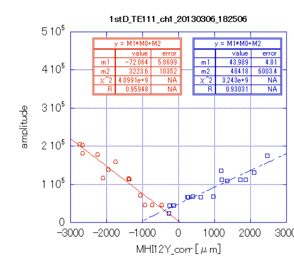

Figure 11: A example of V-shape response of TE111-1(b).

These all data are plotted in Figure 12, and electrical center is (x, y) = (4001±397.5 μm, -1229±119.6 μm) and (x, y) = (3831±209.0 μm, -1262.9±80.82 μm) for HOM1 and HOM2 respectively.

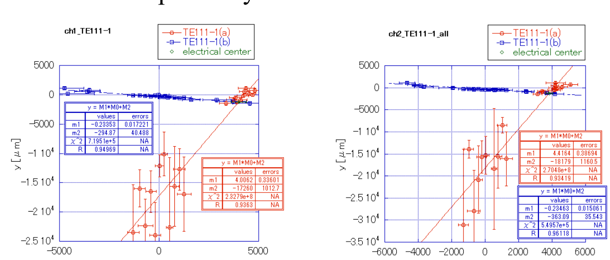

Figure 12: Electrical centers of TE111-1 when RF power into 9-cell superconducting cavities was turned off.

The electrical center of TE111-1 was changed by the change of gradient of SC cavities. We think that RF kick effect caused error of beam position estimation.

CONCLUSION

We could estimate electrical centers of TE111-1 and beam pipe modes by using beam sweep and HOM signal detection at STF accelerator. However, the results are required to make deep consideration of electrical center shift from mechanical center by the HOM coupler antenna arrangement, and their beam kicked effect. The further consideration and further experiment are still required.

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