ALIGNMENT DETECTION STUDY USING BEAM INDUCED HOM AT STF

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Abstract

STF accelerator using L-band photocathode RF Gun and two superconducting (SC) cavities was operated in 2012-2013 for R&D of ILC [1] [2]. An electrical center position of HOM signals from the SC cavities to detect their tilt and bending were tried to measure as a response of beam trajectory sweep. The electrical center detection of a TE111-1 (trapped mode) and a beam pipe mode were succeeded in one of SC cavities by using V-shape response of HOM signal amplitude.

INTRODUCTION

Cavity alignment requirements for ILC are less than 300 μm offset and 300 μrad tilt with respect to cryomodule axis [3]. It is necessary to measure their offset and tilt inside of cryomodule, and to confirm their alignment quality. Cavity offset has been already measured by using beam induced HOM signals at FLASH in DESY [4] [5] [6] [7] [8]. TE111-6 mode which has high impedance was used to estimate cavity offset. However, a cavity deformation by assembly and by thermal contraction during cool down has not been examined yet.

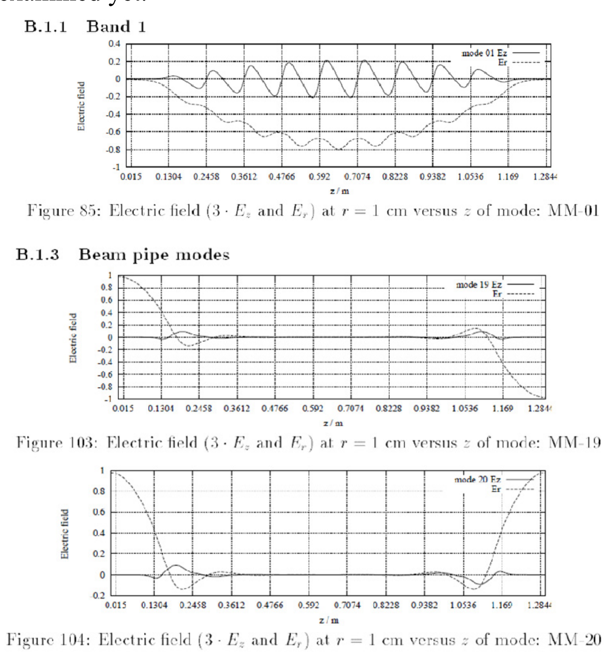

Figure 1: Electric fields of a trapped mode and a beam-pipe mode in a TDR-like TESLA 9-cell cavity calculated with magnetic boundary by R. Wanzenberg [9].

To find cavity tilt and bending, we selected π/9 mode (TE111-1, trapped mode) in the first dipole mode band and beam pipe modes which are located at both end-group of the SC cavity. From information of TE111-1 (~1.609 GHz) which has maximum radial electric field in the middle cell as shown in Fig.1 [9], 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 (~2.100 GHz). Electric fields of beam pipe modes are also shown in Fig.1. Combinations of these electrical centers of localized modes give us cavity tilt and bending information.

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EXPERIMENTAL SETUP

Electron beam extracted from the L-band photocathode RF Gun is accelerated to 40 MeV by two superconducting cavities [10]. Figure 2 shows beam line layout. 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.

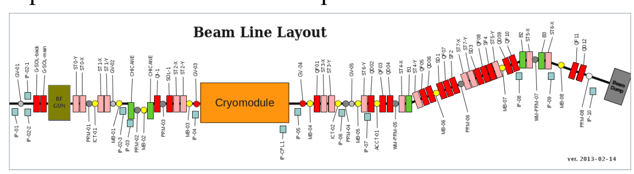


Figure 2: Layout of Beam line. The L-band photocathode RF Gun (green box) is in the left. Two SC cavities are in the cryomodule (orange box).

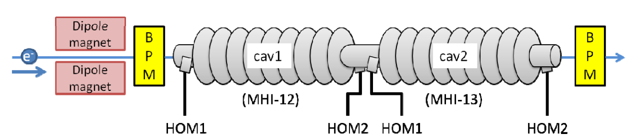


Figure 3: Simplified Layout of HOM detection. An electron beam comes in from the left through dipole magnets, beam position monitor (BPM), two SC cavities, and another BPM.

In this paper, we call two cavities as cav1 and cav2, as shown in Fig.3. Both cavities have two HOM couplers (HOM1, HOM2). 21-meter-long coaxial cables connect HOM couplers and an oscilloscope (Agilent Technologies DSO9404A). Two high pass filters (HPF) and a BPF are used to detect TE111-1 and an IQ converter circuit is 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. Base-line clipping circuit and averaging the signal over bunches are used in BPM. Their gate width is 30 ns. These BPMs located at upstream of cav1 and at downstream of cav2. Two dipole magnets are located in front of the upstream BPM. One kicks beam X direction (horizontal axis), the other one kicks beam Y direction

ISBN 978-3-95450-122-9

(vertical axis). From two BPM data, we estimate beam pass positions at cav1 and cav2. The beam position from these BPM is 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.

Dipole modes are excited by off-axis beams and their amplitude are proportional to beam position [4]. When beam is kicked 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. There are different polarized dipole modes. A vertex of different polarized dipole modes' axis indicates an electrical center. Figure 4 shows conceptual diagram of detecting an electrical center. A diagonal beam sweep is necessary to determine an electrical center.

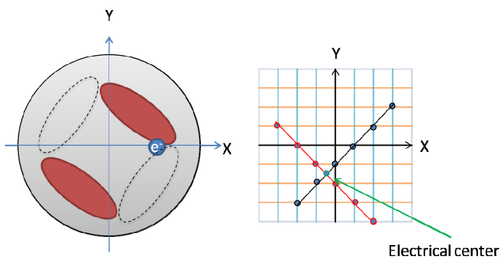


Figure 4: Conceptual diagram of detecting an electrical center.

DETECTION OF INDUCED HOM

The 1st Dipole Mode Band (Trapped Mode)

To examine the 1st dipole mode band, we use two HPF (Mini-Circuits VHF-1500+) and a band pass filter (BPF) which pass only from 1.590 to 1.802 GHz. We observed V-shape response for all of 1st dipole mode band by sweeping a beam in a transverse direction. Theses modes are summarize in Table 1. In this paper, we only use data from HOM1 in cav1 about TE111-1. An example of raw signal after the BPF is shown in Fig.5. Figure 6 shows an example of TE111-1 spectrum after FFT conversion. We labelled different polarized two peaks as a and b in frequency order.

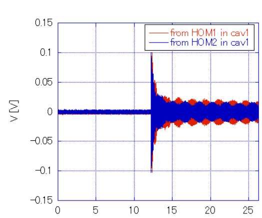


Figure 5: The 1st Dipole Raw Signal after BPF.

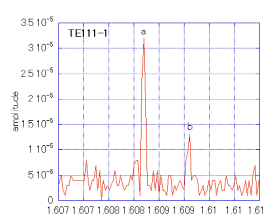


Figure 6: FFT of data from HOM1 in cav1.

Figure 7 which is a plot of amplitude normalized by beam intensity vs. x position in the middle of cav1 shows clear V-shape response. By dividing two slope parts and making linear fitting, we get a point where amplitude is on its minimum. All points (two polarizations and X-Y sweeping) we got were shown in Fig.8. A crossing point in Fig.8 indicates an electrical center (x = 1179±725.6 μm, y = -705.9±186.0 μm).

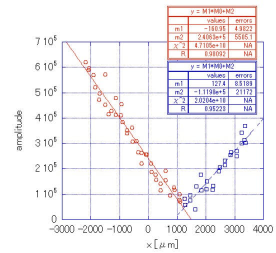


Figure 7: V-shape response of TE111-1(a).

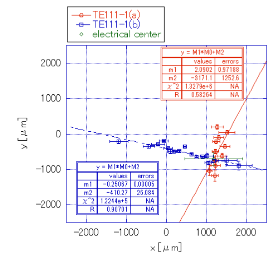


Figure 8: Mapping plot of TE111-1.

Table 1: Observed frequencies of TE111-n

#	n		Frequency [GHz]	#	n		Frequency [GHz]
1	1	a	1.608696	10	6	a	1.693306
2		b	1.609573	11		b	1.693573
3	2	a	1.614571	12	7	a	1.723061
4		b	1.615334	13		b	1.723442
5	3	a	1.625519	14	8	a	1.753731
6		b	1.626205	15		b	1.754112
7	4	a	1.642990	16	9	a	1.782913
8		b	1.643486	17		b	1.784935
9	5	a	1.666412				

Beam Pipe Modes

We used an IQ converter as shown in Fig.9 to measure beam pipe modes. Frequency of beam pipe mode calculated for TDR-like TESLA 9-cell cavity is 2.288 GHz, however there is no signal in KEK cavities. Instead, V-shape response signal was found at 2.100 GHz. We assumed that these are beam pipe modes.

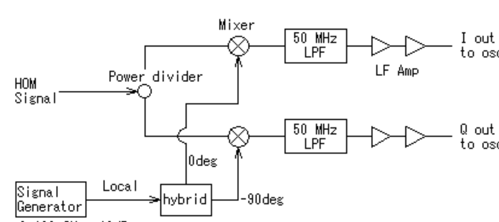
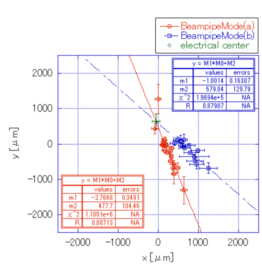


Figure 9: Schematic diagram of IQ Converter.

Signal generator was set to 2.100 GHz, 10 dBm in power and the LPF was set to 50 MHz. There are 4 peaks behaving like dipole mode for HOM1 in cav1. For HOM2 in cav1, there are 10 peaks behaving like dipole mode. In both case, we analyze only two closed peaks which shows clear V-shape response. The results are summarized in Table 2. Assumed that these are beam pipe mode and have maximum amplitude at location of HOM coupler 1 for the cav1, at location of HOM coupler 2 for the cav1, we estimated beam passing position and got points where the amplitude is on their minimum. Figure 10 and Figure 11 show mapping plots which indicate that their electrical centers are (x, y) = (-57.40±95.20 µm, 636.5±212.7 µm) and (x, y) = (311.1±126.2 µm, -583.0±52.91 µm) for HOM1 and HOM2 respectively.

Table 2: Observed frequencies of the beam pipe mode

		ΔFrequeny [GHz] from 2.100 GHz
HOM1	a	0.028
HOM1	b	0.033
HOM2	c	0.020
HOM2	d	0.021



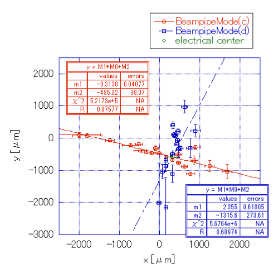


Figure 10:HOM1 mapping. Figure 11:HOM2 mapping.

ALIGNMENT DETECTION

The preliminary measured electrical center for trapped mode and beam pipe modes are shown in Fig. 12 as a function of cavity longitudinal position (z). 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.

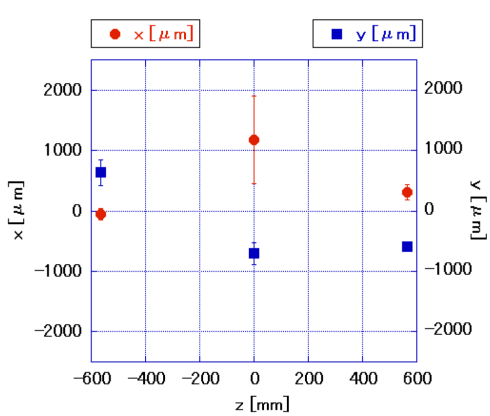


Figure 12: Preliminary alignment detection results of cav1, plotted along the cavity z-axis.

Axis of two BPM positions is a reference for these alignment detection. However, the results is required to make deep consideration of electrical center shift by the HOM coupler antenna arrangement, and beam kick effect by the input coupler RF field. To know detail alignment with respect to a cryomodule, we need to examine field perturbation by bead-pull measuring and simulation calculation about RF kick field. Consequently, the Fig.12 is a preliminary result without consideration of these effect.

CONCLUSION

HOM detection study was performed at the STF accelerator. The 1st Dipole mode (trapped mode) and beam pipe modes were successfully detected. They show reasonable V shape response. Using these minimum points of V shape, cavity alignment and bending were preliminary estimated. The further studies are required to confirm their electrical center shift from the real cavity axis center.

ACKNOWLEDGMENT

The authors greatly acknowledge to all the member of the STF accelerator for the support of the accelerator construction and operation, and the cooperation of this HOM signal measurement. The encouragement and the strong support of the Accelerator laboratory director, K. Oide, the LC promotion office director, A. Yamamoto, and the Quantum-Beam project leader, J. Urakawa are appreciated. The authors also thank to K. Watanabe for his technical detail discussion.

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 ISBN 978-3-95450-122-9