SIMULATIONS AND MEASUREMENTS OF BEAM PIPE MODES EXCITED IN 9-CELL SUPERCONDUCTING CAVITIES

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Abstract

Dipole modes excited in 9-cell superconducting cavities have been studied to evaluate cavity alignment, since their magnitude is proportional to beam offset from their electrical centers. Detection of cavity alignment deviation is important for the ILC superconducting linear accelerator to confirm alignment accuracy of cavities inside cryomodules and to identify a possible source of emittance growth. We are particularly interested in beam pipe modes (BP) because they are localized in both ends of the cavity and can give information on the cavity tilt and bending. We will present beam pipe mode simulations for a KEK cavity and beam response measurements for a TESLA cavity.

BEAM PIPE MODES

Beam pipe modes for an ideal TESLA cavity were calculated by R. Wanzenberg with the computer code MAFIA [1]. Two beam pipe modes appeared at 2.288 GHz, when boundary conditions are that the longitudinal electric field are zero at both ends of the cavity, called magnetic boundary conditions (MM).

We measured beam-induced higher order modes (HOM) in the STF accelerator at KEK in 2012 – 2013 [2]. From the results of the measurement, we found some modes whose behaviour are like dipole mode at around 2.1 GHz [3] instead of 2.288 GHz (MM). The design of cavities used in STF (KEK cavity) is slightly different from the one of the TESLA cavities. In order to confirm them as beam pipe modes and to compare the measurement with the calculation, we conducted the calculation of beam pipe modes of KEK cavity. We also measured the beam induced HOM inside a TESLA cavity at the FLASH linac at DESY, as a function of the beam offset.

SIMULATIONS

The calculation of beam pipe modes for the KEK cavity was conducted by CST MICROWAVE STUDIO 2012 (CST) [4] and HFSS 12 (HFSS) [5] independently.

CST MICROWAVE STUDIO 2012

We simulated beam pipe mode for two models:

- Model 1: KEK cavity without end groups as shown in Fig.1
- Model 2: Model 1 with added ports outer conductors (two HOM cups, outer conductor of input coupler and outer conductor of pick-up port), without HOM couplers, pickup antenna and inner conductor of input coupler, as shown in Fig.2.

Eigenmode solver is used for both models.

At first, Model 1 was simulated to compare with the simulation calculated by R. Wanzenberg since his model has only symmetric construction, so that the beam pipe is just cylindrical. The frequencies of two beam pipe mode at same frequency are 2.237 GHz for Model 1 when MM boundary conditions are defined. When the longitudinal magnetic fields are zero at both ends of the cavity (EE; Electric boundary conditions), there is no dipole mode from 2^{nd} dipole mode passband to 1^{st} quadrupole mode passband. This result are corresponded with one calculated by R. Wanzenberg except for the frequencies of beam pipe modes. However differences of frequencies are only 51 MHz.

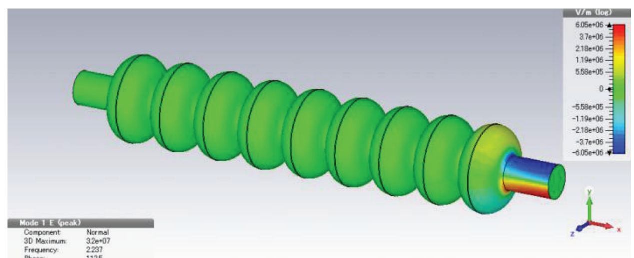

Figure 1: Model 1 (KEK cavity).

In the next step, we invested frequencies of beam pipe modes for more realistic model, Model2. The frequencies of beam pipe modes for Model 2 are 2.067 GHz and 2.194 GHz under MM boundary conditions. When EE boundary conditions are defined, dipole mode appears at 2.169 GHz. These frequencies are near 2.1 GHz found from measurement at STF.

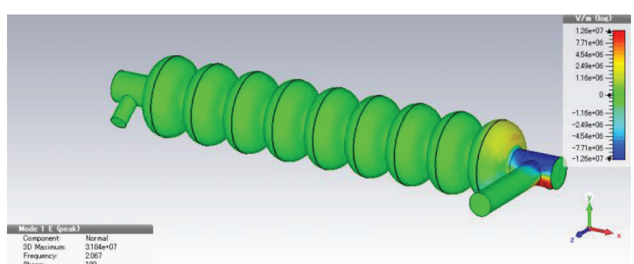

Figure 2: Model 2 (KEK cavity with ports outer conductors).

The frequencies of beam pipe modes become lower by attaching ports outer conductors and furthermore one mode is added. We can expect that the frequencies of beam pipe modes for TESLA cavity also become lower than 2.288 GHz by attaching ports outer conductors and an existence of the other mode. We will simulate TESLA cavity with ports outer conductors in the next.

HFSS 12

Model 2 are also simulated by HFSS 12. Solution type is Eigenmode. A beam pipe mode appears at 2.194 GHz. Figure 3 shows electric field distributions of a mode at 2.194 GHz. The other frequencies calculated by CST do not appear so far. The reason is not clear. We will make simulation accuracy precious.

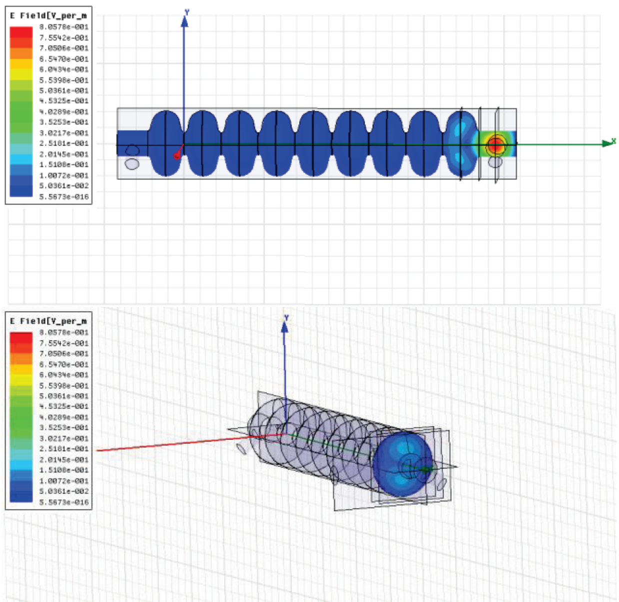

Figure 3: Model 2 calculated by HFSS 12.

Frequencies of Beam Pipe Modes

Table 1 summarizes these results of simulations for KEK cavity shape. More precious simulation is required to know the electrical center relative to the mechanical center.

Table 1: Frequencies of Beam Pipe Modes

Model	Code	Frequencies of BP
Model 1	CST	2.237 GHz , 2.237 GHz (MM)
Model 2	CST	2.067 GHz (MM) 2.169 GHz (EE) 2.194 GHz (MM)
Model 2	HFSS	2.194 GHz

MEASUREMENT OF TESLA CAVITY

We measured beam induced HOM in the 8th TESLA cavity (Cav8) in the 7th (and last) cryomodule (ACC7) at FLASH. Cav8 is located at the downstream end inside ACC7. Figure 4 shows the FLASH layout [6]. During this experiment, single bunch operation was performed and bunch charge was 0.52 nC. Table 2 shows the input power of RF-gun and acceleration voltage of the cryomodules during the beam operation.

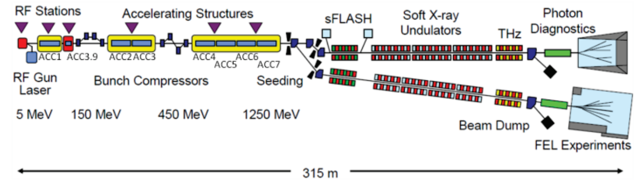

Figure 4: Layout of FLASH accelerator. ACC7 is located at the end of the accelerator.

Table 2: Input Power and Acceleration Voltage

Module	Input Power/ Acceleration Voltage
Gun	3.98 MW
ACC1	155.4 MV
ACC3.9	10.0 MV
ACC2/3	331.9 MV
ACC4/5	207.8 MV
ACC6/7	291.0 MV

An oscilloscope (Tektronix TDS6604B) was used to capture HOM waveforms. Two high pass filters (VHF-1600) which can cut off the main RF power (1.300 GHz), three amplifiers (ZX60-6013E-S+, total gain; 45 dB) and a band pass filter from 2.100 GHz to 2.210 GHz were inserted in front of the oscilloscope. One waveform data has 200 k points with 5 GS/s. Figure 5 shows a typical raw waveform data taken by the oscilloscope.

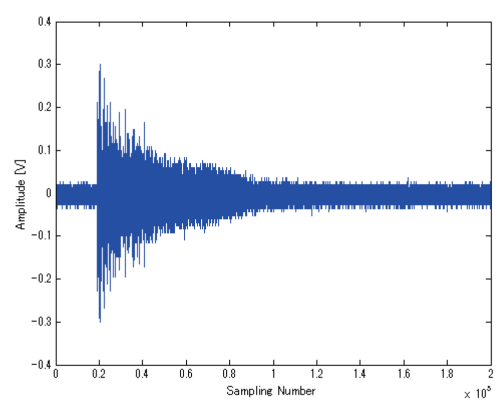

Figure 5: An example of HOM waveform.

Figure 6 shows a plot of FFT of HOM waveform. The frequency step is about 20 kHz. Legends in Figure 6 indicate x positions of beam at the nearest beam position monitor (BPM) to ACC7 Cav8, named 11ACC7 which is located at downstream of ACC7. We changed the beam offset by a dipole magnet located at upstream of ACC7. Table 3 shows beam positions of a BPM located at upstream of ACC7 named 9ACC6 and 11ACC7 at downstream of ACC7.

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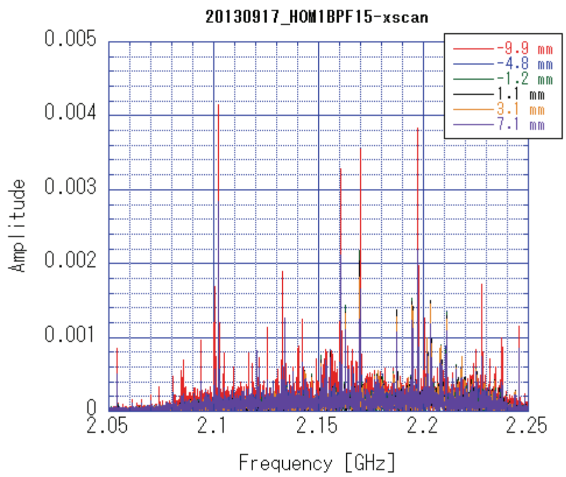

Figure 6: HOM FFT spectrums for different beam offsets.

Table 3: Beam Position

#	(x, y) @9ACC6	(x, y)@ 11ACC7
1-1	(0.3 mm, -1.0 mm)	(1.1 mm, -3.0 mm)
1-2	(0.4 mm, -1.1 mm)	(-9.9 mm, -2.8 mm)
1-3	(0.3 mm, -1.0 mm)	(-4.8 mm, -3.0 mm)
1-4	(0.3 mm, -1.0 mm)	(-1.2 mm, -3.0 mm)
1-5	(0.3 mm, -1.0 mm)	(3.1 mm, -2.9 mm)
1-6	(0.4 mm, -0.9 mm)	(7.1 mm, -2.7 mm)

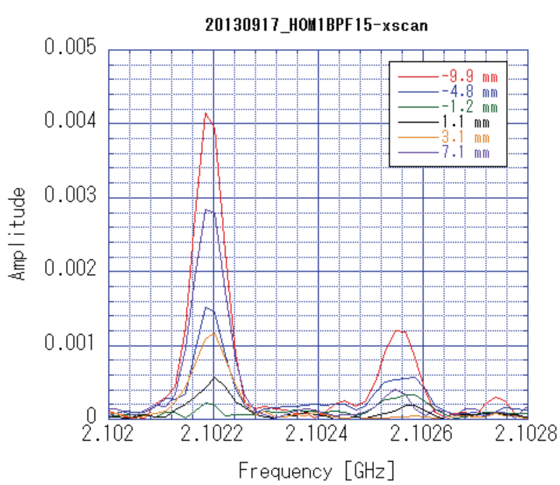

Figure 7: HOM spectrums at around 2.102 GHz region.

Figure 7 is a zoomed view at around 2.102 GHz region of HOM FFT spectrum shown in Fig. 6. In Figure 8, the amplitudes of the 2.1022GHz peak with respect to x beam position for 11ACC7 BPM are shown. Their response is V-shaped, proving the dipole character of this mode, with its minimum at -1.1 mm position. This mode is expected to be a beam pipe mode. To estimate more precisely the electrical center of this mode, and therefore the cavity position, more measurements are required.

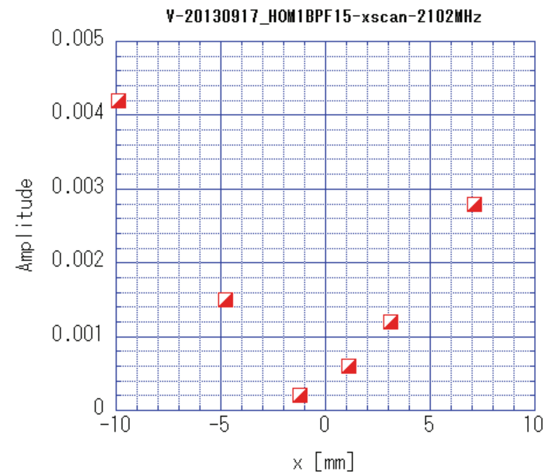

Figure 8: Amplitudes response of 2.1022GHz peak in Figure 7, with respect to x beam position.

CONCLUSION

We simulated beam pipe mode for KEK cavity. And beam induced beam pipe mode detection experiment was performed for TESLA cavity at FLASH at DESY. The calculated beam pipe mode frequencies are close to the measured beam pipe mode frequency for KEK cavity at STF. Some dipole-like modes, believed to be beam pipe modes, are found for TESLA cavity and their frequencies are almost same for KEK cavity.

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