THE DESIGN STUDY FOR LOW-Q IP-BPM

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Abstract

Beam position monitors (BPMs) with a resolution in a few nanometers range are required to control beams in the locations that are close to the interaction point (IP) of the International Linear Collider (ILC). ATF2 at KEK has considered as a test facility to investigate this requirement. In order to measure beam position stability at ATF2 final focus, a kind of IP-BPM has been developed at KEK and it has been tested in the ATF extraction line. We have designed an IP-BPM with lower Q-value than the IP-BPM in the extraction line in order to achieve smaller resolution. It enables easier separation of individual bunches in a multi-bunch signal. We have performed the design study for IP-BPM by using of the electromagnetic simulation program MAFIA and HFSS. The designed IP-BPM consists of one cell sensor cavity and one cell reference cavity. The results of the design studies showed signal decay time of 20 ns and the resolution of a few nm. We present the results of design studies in which include effects of common mode contamination in the IP-BPM, as well as preliminary test results on the proto-type IP-BPM.

INTRODUCTION

The ATF2 will address two major challenges of the ILC BDS: focusing the beams to nanometer size and providing sub-nanometer stability[1]. The IP-BPM is required to have a resolution in order to be able to measure position jitter within a few nanometers in the vertical plane. Care designs are needed to suppress effects which limit the fine resolution, such as coupling from the horizontal beam position and contamination from the beam angle signal.

In ATF extraction beam line, an IP-BPM to test these effects was already installed and tested by KEK. We have performed a design for an IP-BPM with lower Q value than the extraction beam line. To achieve the small loaded Q for the resolution with a few nm, we employ larger coupling slot size in sensor cavity and stainless steel as a cavity material in reference cavity. A cold model for the IP BPM was fabricated and it's rf measurement is on the point of performing.

In this paper, we describe the results of design studies and preliminary test for the IP-BPM. In section 2, the overview of ATF IP-BPM is introduced. Section 3 and section4 describe the calculated properties for IP-BPM and common mode contamination, respectively. In section 5, preliminary test results of the fabricated IP-BPM are shown and finally, in section 6, a summary will be given.

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OVERVIEW OF ATF IP-BPM

ATF IP-BPM is rectangular cavity to separate x and y signals. In addition, ATF IP-BPM has small cavity length to be insensitive to the beam angle and small aperture to improve the orbit sensitivity. Frequencies for x and y dipole modes, that are independent to the cavity length, are 5.712 GHz and 6.416 GHz, respectively. Figure1 shows that dipole mode frequencies are well separated from other modes including TE_{111} and TM_{111} whose frequencies are depend on the cavity length.

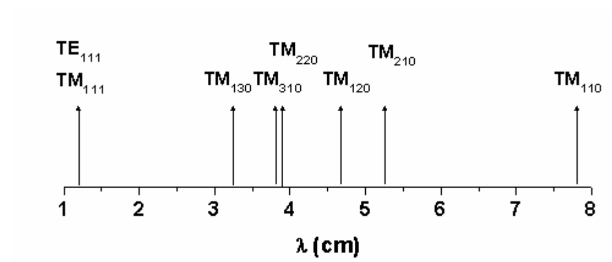

Figure 1: Mode spectrum of ATF IP-BPM. TM210 and TM120 indicate x dipole and y dipole modes, respectively.

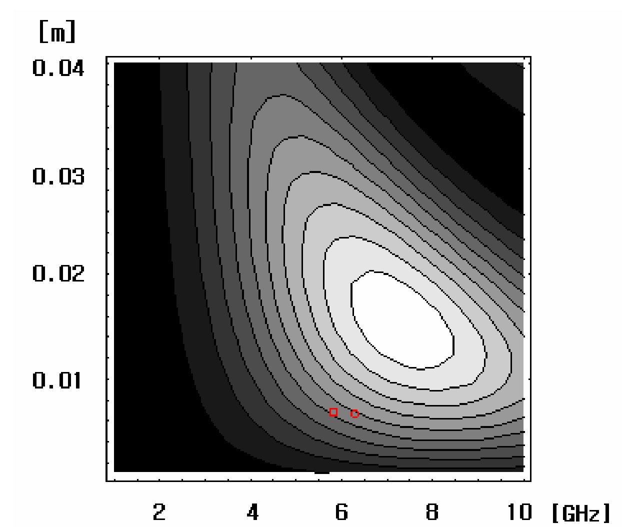

Figure 2: The generated dipole mode energy. Assumed bunch length is 8 mm rms. Marks of rectangular and circle indicate cases of x dipole and y dipole, respectively.

The generated dipole mode energy in cavity length and frequency space is calculated and shown in Fig.2. In the figure, the operation points of ATF IP-BPM are marked. Although there is no global optimal dipole frequency for each BPM application, the effectiveness of operating

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frequencies for ATF IP-BPM can be roughly estimated from Fig.2. Since small cavity length (6 mm) had to be considered to decrease the sensitivity for beam angle, the higher frequency than operating frequencies seem to be ineffective in the aspect of generated energy.

Main cavity parameters of ATF IP-BPM are compiled in Table 1. Beside that, signal decay times for x and y are about 110 ns and 60 ns, respectively.

Table 1: ATF IP-BPM parameters

Port	f (GHz)	β	Q0	Qext
x	5.712	1.4	5300	3901
y	6.426	2	4900	2442

A DESIGN FOR LOW-Q IP-BPM

We had performed the design of an IP-BPM which consists of one cell sensor cavity and one cell reference cavity. Basic idea of ATF IP-BPM was employed in the design. To get faster time resolution, larger coupling slot in sensor cavity and larger lossy cavity material in reference cavity were considered. The design values of the IP-BPM, which satisfy 20 ns decay time for x and y signal in sensor cavity and 30 ns decay time in reference cavity, are shown in Table 2.

Table 2: Design value for KNU IP-BPM

Port	f (GHz)	β	Q0	Qext
x (Sensor)	5.712	8	5900	730
y (Sensor)	6.426	9	6020	670
Reference	6.426	0.002255	1205	534550

Figure 3 shows the calculated output signals. In the calculation of the output signal, ATF beam parameters are used. The resolution of the cavity BPM are determined by

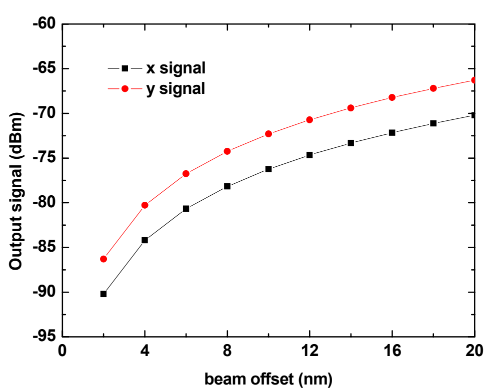

Figure 3: Calculated output signal vs. the beam offset.

thermal noise. The thermal noise power for the designed IP-BPM is given by [2]

$$P_{TN}[dBm] \approx -174 + 10\log\Delta f,$$

where Δf is ~25 MHz for both x and y signals. Therefore, the resolution below the 2 nm can be principally expected by Fig. 3 and calculated thermal noise power.

COMMON MODE CONTAMINATION

When beam goes through the cavity BPM, monopole mode (common mode) signal as well as dipole mode signal used in detecting beam position are excited as shown in Fig. 4. Since the signal of monopole mode is extremely larger than dipole mode signal from 1 nm beam offset, the signal of monopole mode is larger than dipole mode in the order of 3 at resonance frequencies of dipole modes. Because of employing larger coupling slot to reduce the signal decay time, designed IP-BPM can be easier to be exposure to this common mode. Although the common mode is excited at 90 degree difference from the dipole mode and can be rejected by phase filtering, it is more desired to select only dipole mode from cavity to waveguide on design stage [3].

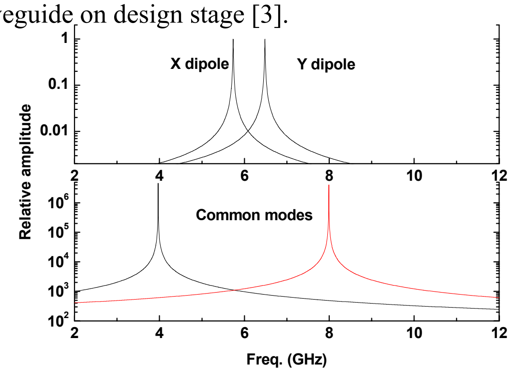

Figure 4: Signal for 1 nm offset in frequency domain.

The rejection of common mode can be easily done by positioning coupling slot appositely. Figure 5 shows the rejection of higher order common mode. However, some errors in coupling slot position can be happen in fabrication. Therefore, it is needed to investigate error

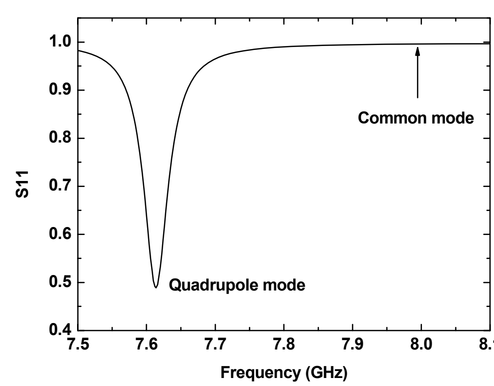

Figure 5: Rejection of higher order common mode.

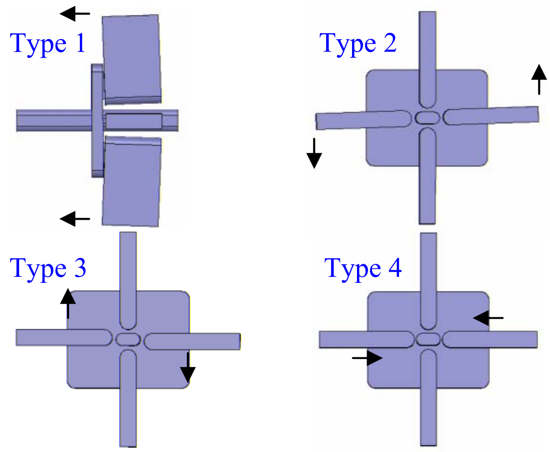

Figure 6: Assumed error types.

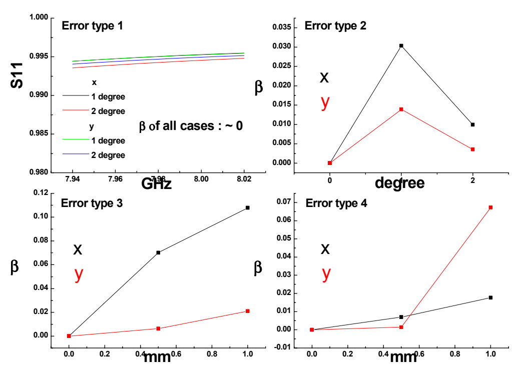

Figure 7: Coupling constant variation of common mode.

effect carefully and various error types are assumed in investigation for common mode contamination as shown in Fig.6. Figure 7 shows the result for the investigation. The degree of assigned errors in the simulation is much larger than real case. If we consider a few um as real error, the designed IP-BPM seems to be safe from the common mode contamination from the result in Fig. 7. However, to clear the results shown in Fig.7, we need to take more data in each error type.

1ST RF MEASUREMENT OF COLD MODEL

The fabrication of the cold model was completed and the main properties of the IP-BPM cold model were measured with a network analyzer. Figure 8 shows the experimental setup for the measurement. The measurement resulta for reflection and transmission are compiled by Table 3 and Table 4, respectively. As shown in tables, the measured frequencies of two dipole modes agreed within 11 MHz but internal quality factor Q0 is unexpected small value. We presume that loose compressing jig cause small beta and Q0. Thus, we plan to measure cavity properties again with prudence.

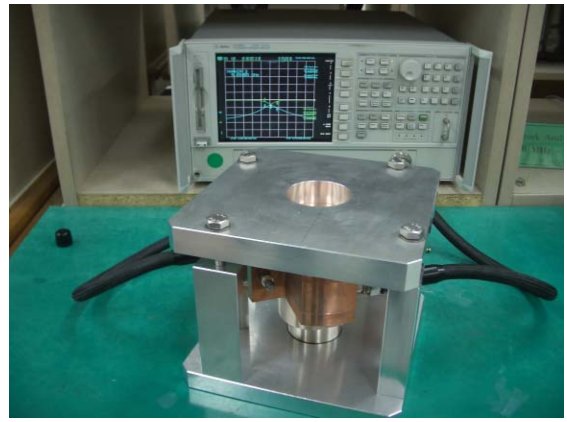

Figure 8: Experimental setup for the measurement.

Table 3: Reflection measurement

Port	f (GHz)	β	Q0	Qext
X11	5.701	0.72	744	1030
X22	5.701	0.73	740	1017
Y11	6.419	0.94	575	609
Y22	6.419	0.99	665	671

Table 4: Transmission measurement

Port	f (GHz)	β	Q0	Qext
X12	5.701	0.59	685	1146
Y12	6.418	0.89	621	785

SUMMARY

We have described the results of design studies for IP-BPM with low-Q value, including the investigation of common mode contamination. We also described the results of the measurement for the IP-BPM cold model. The measured frequencies of two dipole modes agreed within 11 MHz but internal quality factor Q0 is unexpected small value. It is presumed that imperfect contact of cavity parts causes unexpected small Q0.

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