BEAM ORBIT TILT MONITOR STUDIES AT ATF2

Daisuke Okamoto[#], Tomoyuki Sanuki, Tohoku University, Sendai

Yosuke Honda , KEK, Ibaraki

Abstract

We have designed a beam orbit tilt monitor for stabilizing a beam orbit in ATF2 as well as future international linear collider. Once we can measure a beam orbit tilt angle with high precision at a particular point, we can evaluate the beam position at the focal point. This monitor is composed of a single rectangular cavity and waveguides to extract the signal. This monitor can measure the beam orbit tilt with a single cavity. We extract the signal of one basic resonance mode from the cavity. This electric field mode is perpendicular to the nominal beam axis, and is excited by beam tilt. The magnitude of extracted signal gives us the beam tilt data. According to our simulation, the expected sensitivity is about 30 nrad.

INTRODUCTION

Generally the orbit tilt is calculated from two position data. We are using the cavity BPMs for detecting the beam position. The angle resolution is dependent on the position resolution and the distance between the two BPMs. For example, when the position resolution at each BPM is 10 nm and distance between the two cavities is 10 cm, angle resolution becomes about 140 nrad. Of course, if the larger the distance is, the better the angle resolution becomes. But when two BPMs are separated widely, the relative alignment of the two BPMs becomes severe.

The tilt monitor simply detects the beam tilt angle solely and we can evaluate the beam position. One cavity measurement will be useful tool in many cases.

PRICIPLE OF THE TILT MONITOR

The Tilt monitor uses monopole mode among resonant modes that beam excites in the sensor cavity.

Monopole mode

In the cavity, electro magnetic fields are expanded as the resonant modes according to boundary condition. Among the resonant modes, TM110 mode is called "monopole mode" in rectangular cavity. Figure 1 shows the monopole mode and its electric filed distribution. Electric filed of the monopole mode is most strong at the center of the cavity and is perpendicular to the nominal beam axis. In case, beam has the tilt angle along to electric field, the monopole mode energy is excited by beam. The excited energy is proportional to the square of tilt angle.
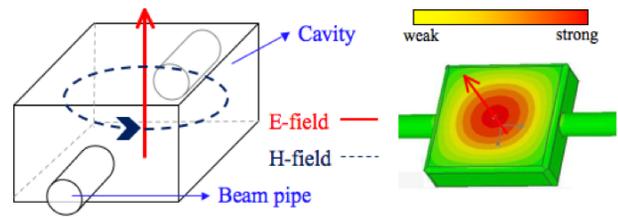

Figure 1: monopole mode of a rectangular cavity

Signal extraction

We extract the magnetic field of the monopole mode from sensor cavity to waveguide through the slit. The slit is along to the magnetic filed of the monopole mode for suppressing mixing of another resonant modes. In the waveguide, the extracted magnetic field is transmitted in the TE mode. The TE mode signal is extracted from the antenna to coaxial cable with 50 Ω impedance. The amplitude of the extracted signal is proportional to tilt angle. We can use this relation for measuring beam orbit angle.
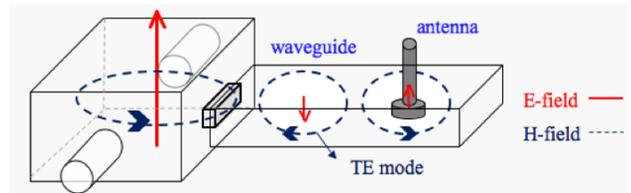

Figure 2:waveguide and antenna to extract the signal

DESIGN OF THE TILT MONITOR

The design was determined by using electro-magnetic calculation software, the MW-studio in CST-studio. (CST inc.)

Sensor cavity

The excited energy of the monopole mode is dependent on the cavity shape. We optimized the size of the rectangular cavity. The height prefers to be smaller due to increase the energy density. The higher energy density leads to the stronger electric field. As the result, the sensitivity to tilt angle becomes better.

The excited energy versus width and length are shown in the figure 3. Excited energy becomes higher when width and length are almost one to one, in fact there is a little difference due to influence of the beam pipe. We chose the length around 100 mm, because the monopole mode frequency was smaller in the larger cavity. There is the frequency condition due to bunch interval. In the multi bunch run at ATF, the bunch interval is 2.8 nsec. Considering the phase matching at each bunch, the following condition is required,

_____

[#]okamoto@awa.tohoku.ac.jp

$$357\text{MHz} \times n (n = 0, 1, 2, \cdots)$$

Designed sensor cavity that is satisfied with above conditions is following. Height and width and length are set to 30.0 mm, 95.0 mm and 103.0 mm. There is the 4mm roundness at the each egg due to considering the making way. Determined frequency of the monopole mode is 2.142GHz(n=6).
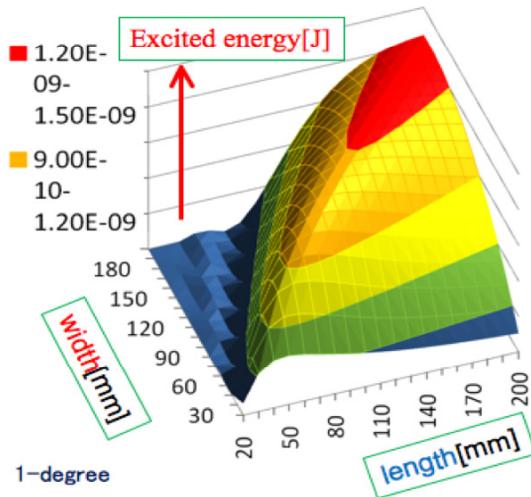

Figure 3: Excited energy versus width and length

Waveguide and antenna

There are also resonant modes in waveguide, because waveguide length is finite. We designed the waveguide as monopole mode frequency is separated from other resonant modes well in the waveguide to avoid the interference. In this design, we set the cut off frequency at 1.5GHz as 2.14GHz signal can be transmitted.

We adjusted the antenna position and depth such that TE mode signal is couple with the antenna. We set the end of the waveguide as the port1 and injected the TE mode signal from port1 as shown in figure 4. We monitored the S11(reflection amplitude) and adjusted the antenna position and depth as the S11 becomes zero at 2.142GHz. The result of the adjustment is represented in figure 5.
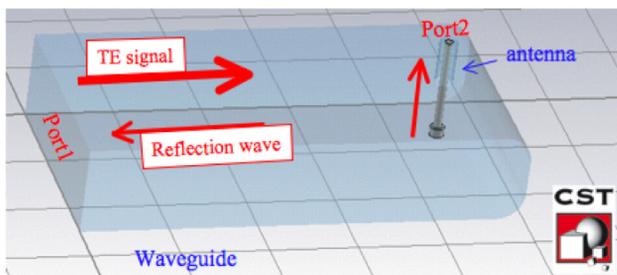

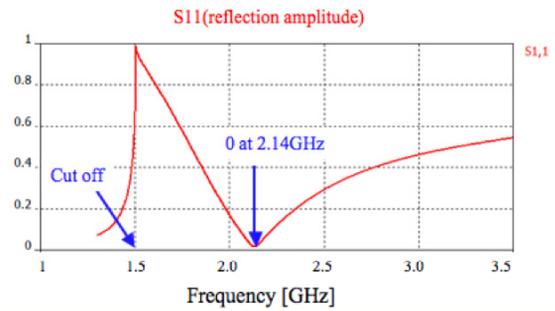Figure 4: Calculation of the S11 parameter

Figure 5: S11 parameter after the tuning

Slit and transmission simulation

The Slit connects the sensor cavity and waveguides. Total structure is represented in figure 6. The monopole mode signal is extracted via two slits for the symmetry and to reduce the coupling of sensor cavity and waveguide. If the coupling is stronger, other modes are likely to mix into the waveguide.
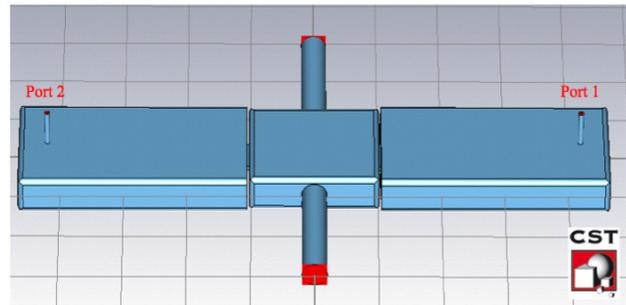

Figure 6: Total structure and ports

Slit design is related to the loaded Q. Loaded Q is the quality factor of a relation between the stored energy U and power P that is lost per angular oscillation of the mode. When angular frequency is ω, this relation is written as

$$Q_L = \frac{\omega U}{P}$$

We determined loaded Q such that the decay time of the stored energy became about 150 nsec. This is the bunch interval of the ILC like beam at ATF2. Determined target loaded Q is 2800. We can calculate the loaded Q and resonant frequency from the transmission amplitude of antenna to antenna. At the each antenna, we set the port. We generated the RF signal at port1 and at the port2, we measured the S21 parameter(transmission amplitude). S21 stands for the resonant curve. Detailed tuning of the resonant frequency was done in this process, because slits change the cavity size a little. As the result of the tuning was shown in figure 7, the resonant frequency became 2.142GHz and S21 became 2784. These are satisfied with the target value.
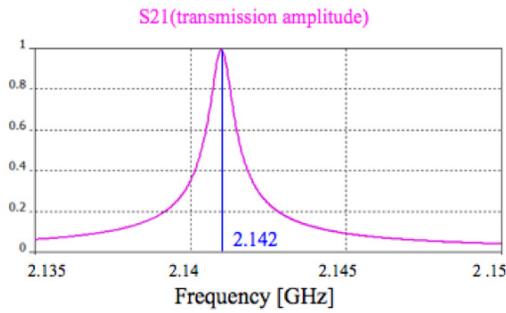
Figure 7: S21 parameter after the tuning

PERFORMANCE

We have to consider the thermal noise to evaluate the sensitivity of the tilt monitor.

Thermal noise

Thermal noise is determined by the temperature T and bandwidth Δf with following relation;

$$P_{TN} = K_B T \Delta f ,$$

where K_B is Boltzmann constant. In case of the room temperature 300K and 3MHz bandwidth, the thermal noise is about 1.24×10^{-14} W.

Sensitivity

We compared the output power and thermal noise as shown figure 8. It was confirmed that the output power is proportional to the square of tilt angle by the figure. The expected sensitivity of tilt monitor was about 30 nrad. We can improve the sensitivity by lowering the detection electronics.
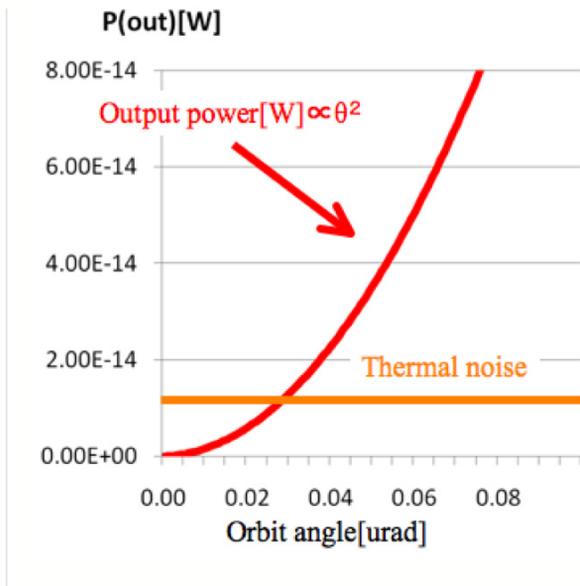

Figure 8: output power from antenna versus orbit angle

3D MONITORING TYPE

We have designed another useful type. This type use the two monopole modes in a rectangular cavity for measuring three dimensional orbit tilt. We can use the horizontal monopole mode in addition to vertical monopole mode. Figure 9 stands for the total structure of this type. There are new waveguides and antennas along to the vertical direction due to extract the horizontal monopole mode.
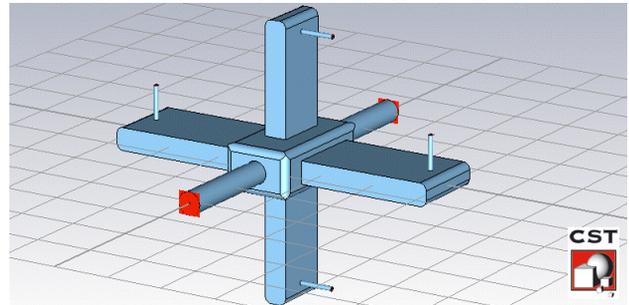

Figure 9: the structure of the 3D monitoring type

We evaluated the sensitivity of the 3D monitoring type too. The sensitivity was about 80 nrad for vertical and 300 nrad for horizontal. There is some getting worth the sensitivity for vertical. Because we had to change the sensor cavity shape such that we could use the horizontal monopole mode with some precision.

SUMMARY

We have studied about beam orbit tilt monitor. This monitor can measure the beam orbit angle very precisely. With this monitor, we can measure the beam tilt with only one cavity. The expected sensitivity was 30 nrad for vertical. This is equivalent to the 3nm resolution at 10cm distance. Thermal noise limits the sensitivity of the tilt monitor. We can improve the sensitivity by lowering the temperature. 3D monitoring type can measure the three dimensional orbit tilts with some precision. This type might be useful commonly.