Nanometer Order of Stabilization for Precision Beam Size Monitor (Shintake Monitor)

T. Kume, N. Terunuma, T. Tauchi, Y. Honda, S. Araki, T. Okugi, J. Urakawa, T. Yamanaka, M. Oroku, Y. Kamiya, et al.

NANOMETER ORDER OF STABILIZATION FOR PRECISION BEAM SIZE MONITOR (SHINTAKE MONITOR) *

T. Kume[#], N. Terunuma, T. Tauchi, Y. Honda, S. Araki, T. Okugi, J Urakawa,
KEK, 1-1 Oho, Tsukuba, Ibaraki, 305-0801, Japan.
T. Yamanaka, M. Oroku, Y. Kamiya, S. Komamiya, T. Suehara,
The University of Tokyo, 7-3-1, Hongo, Bunkyo, Tokyo, 113-0033, Japan.
B. Bolzon, A. Jeremie, N. Geffroy, IN2P3-LAPP, Annecy-le-Vieux, France.

Abstract

A precision beam size monitor using interference fringes as a reference called Shintake monitor[1] has been developed. Relative position between the beam and the interference fringes should be stabilized within few nm to measure the beam size of 37 nm with resolution of better than 10%. This paper presents concept and performances for stabilization of the Shintake monitor with respect to vibrations. We stabilized the table for the interferometer using a method, "Rigid mount on floor", and the table motions relative to the floor are estimated to be 2 and 6 nm

INTRODUCTION

The ATF2 final focus test beam line has been constructed[2], aiming to confirm techniques for future particle accelerators such as the International Linear Collider (ILC)[3]. Techniques related for obtaining nm order of focused beam and for realizing nm order of beam position control are to be developed.

Shintake monitor is a precision beam size monitor which has nm order of resolution, using interference fringes of laser as a reference. Figure 1 shows schematics of the Shintake monitor. Two laser beams, divided from a frequency stabilized laser, make interference fringes in their crossing space. Electron beam to be measured irradiates the fringes perpendicular to their grating vector. Photons in the fringes are scattered by the electron beam (inverse Compton scattering) and the number of the scattered photon is detected by gamma ray detector. If the electron beam is scanned against the fringes, the number of scattered photons is modulated by the fringe interval and the beam size. Electron beam size can be obtained from the modulation depth of the photon numbers.

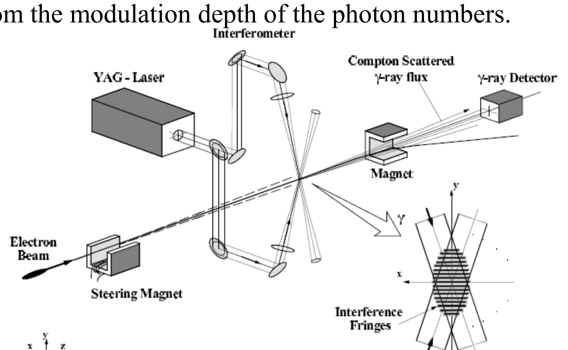

Figure 1: Schematics of the Shintake monitor.[1]

*Work supported by KEK.

#tatsuya.kume@kek.jp

In ATF2 electron beam having ultra low emmitance obtained from the damping ring of the ATF is focused to 37 nm (σ) for its vertical direction and 2.8 μm (σ) for its horizontal direction, respectively. The Shintake monitor is expected to measure the vertical beam size with the resolution of better than 10% at the virtual interaction point (IP) of the ATF2, that is the focal point of the final focusing magnet.

CONCEPTION FOR STABILIZATION

In order to realize the resolution expected for the Shintake monitor, it is necessary to stabilize relative position between the beam (as an object) and the interference fringes (as a reference) within a few nm. It is difficult to detect their relative position with nm of accuracy; however, the beam can be considered to fluctuate coherently with the final focusing magnet, and the fringes can be stabilized against the interferometer with precise phase control[4]. Therefore, the beam and the fringes can be stabilized indirectly, based on relative position stability between the interferometer and the magnet. This is our basic conception for stabilization.

There are three methods for ensuring relative position stability between the interferometer and the magnet as

- Rigid mount on floor,
- Mount on a common table,
- Position feedback.

"Rigid mount on floor" is to use individual rigid mount for supporting the interferometer and the magnet, respectively. This is based on the floor rigidity, that is coherence for vibration between the interferometer and the magnet. The support is expected to be tolerant to slow floor motion, and has simple structure resulting low cost; however, it can be affected by fast floor motion. "Mount on a common table" is to use a common table with anti-vibration mount for the interferometer and the magnet. It can not be affected by any floor motion; however, it needs costly large and rigid common table and its anti-vibration mount. "Position feedback" is to measures relative position between the interferometer and the magnet and to stabilize it through active feedback or post processing. It can not be affected by any disturbance; however, it needs R&Ds for obtaining nm order of relative position accuracy for approximately 1 m distance between the interferometer and the magnet.

We adopted "Rigid mount on floor" for the first trial, considering schedule and cost for constructing ATF2. Here, we expected that there would hardly exist fast floor motion (> a few 10 Hz) with considerably large amplitude (> a few nm). This is based on the floor motion of the ATF constructed upstream of the ATF2 in advance. We also expected that slow floor motion (< a few 10 Hz) is coherent between the interferometer and the magnet. This is because the distance between them is enough small (approximately 1 m) and the floor between them is stiff enough to make their motion coherent for slow floor motion. The floor of the ATF2 was expected to be rigid enough and stable, being made of iron reinforced 50 cm thick concrete with 1.2 m thick lattice ribs supported by 13 m long iron reinforced concrete piles.

VERTICAL TABLE FOR THE SHINTAKE MONITOR

It is important to ensure rigidity and consider vibration responses for both the Shintake monitor and the final focusing magnet[5], as their distortions and resonances will affect relative stability between them. The Shintake monitor has more components and consequently more degrees of freedom to consider in the designing. In this paper, we focus on the consideration for the Shintake monitor.

Figure 2 shows our newly designed interferometer for the Shintake monitor. Laser beam is derived from a laser table out of the interferometer through an aperture A. It makes interference fringes with their grating vector parallel to the page around the center of a vacuum chamber M, where the beam size is measured. The electron beam to be measured goes through the center of M perpendicularly to the page. The interferometer is set vertically on floor, as the electron beam goes horizontally in the ATF2.

The interferometer is designed with laser crossing angle of 2, 8, 30 and 174 deg, in order to change the period of the interference fringes remotely. This is to measure beam size consecutively from a few 10 nm to a few µm during beam operation; however, it requires large space and heavy load for parts mounting. The total weight of parts is estimated to be 200 kg. The vacuum chamber M, being the heaviest with approximately 100 kg needs a mount hole near the center.

Being rigid enough not to be affected by distortions and resonances, having mounting space of 1.7 m * 1.6 m, supporting 200 kg of load, and being set vertically on floor, a vertical table for the interferometer was designed with total thickness of 250 mm, putting steel honeycomb core into 2 pieces of 5 mm thick non-magnetic stainless steel plates. The vertical table is mounted on a horizontal table having thickness of 394 mm for coarse height adjustment. The horizontal table was also made with the same structure. They are bolted on the floor rigidly with two supporting bars made of non-magnetic stainless steel, using shims under them for fine height adjustment. They are set on the IP with position accuracy of +/-1mm, with the mount side of the vertical table facing toward down stream of the electron beam.

Figure 3 shows photographs of the vertical table with the horizontal table and the supporting bars. It has dimension and weight of approximately 2*2*2 m and 1900 kg, respectively. Figure 4 shows its compliance curve without any parts on. It was obtained from impulse response measurements on the flat base plate shown in fig.3 (right), and not bolted on the plate (quasi-freely set

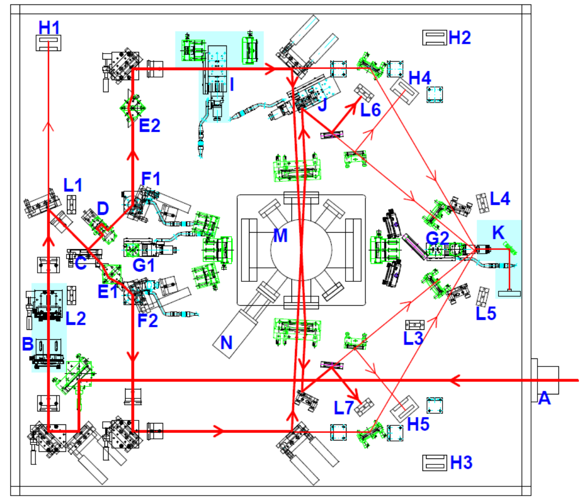

Figure 2: Interferometer for the Shintake monitor. Red lines show optical path for the interferometer having 174 deg of crossing angle.

Figure 3: Vertical table with a horizontal table and bars for supporting them. They are views from the mount side (left) and the back side (right). The square hole on center is for mounting the vacuum chamber.

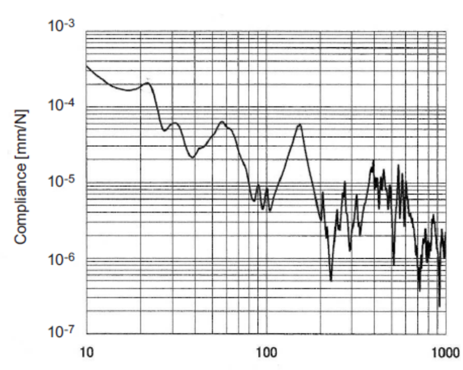

Figure 4: Compliance curve for the vertical table with the horizontal table and support bars obtained from impulse response measurements by Herz Co. Ltd.

on the base plate). One can see several peaks in Fig. 4. It was speculated that two peaks appearing form 20 to 30 Hz arise from the base plate, considering the size of the table and the base plate, and that peaks appearing over 200 Hz arise from back ground noise in measurement. The two peaks appearing between 50 and 60 Hz and between 100 and 200 Hz are speculated to be normal mode of the table.

VIBRATION MEASUREMENT

After setting the table on the IP and installing the interferometer, vibration of the floor and top of the vertical table were measured simultaneously. Here, a velocity sensor CMG-40T by Guralp Systems for lower frequency range from 0.2 to 13 Hz and an acceleration sensor MG-102S by Tokkyokiki for higher frequency range from 13 to 100 Hz were used. We measured twice with an interval of about 5 months. We focus on the results for vertical direction as the Shintake monitor measures the vertical beam size.

Fig. 5 shows the power spectrum densities (PSDs) of the floor motion. The two spectrums have similarity with a peak around 3 Hz, which is from ground of the ATF2, i.e. the geological resonance. The second measurement is about 1 order higher than the first one. This is caused by daily change in the background vibration.

Fig. 6 shows transfer functions of the table, coherence functions between the floor and the table and table motions relative to the floor, respectively. Both the transfer functions and the coherence functions obtained from the two measurements agree well with each other. It means that they are fairly accurate, having good reproducibility. The transfer functions are continuously 1 up to nearly 40 Hz. It means that there is no amplification of vibration on the table. The coherence functions are also continuously 1 up to nearly 60 Hz, which means that the floor and the table move coherently.

Table motions relative to the floor estimated from the two measurements are different. This is speculated to be caused by difference in floor motion shown in fig. 5, affected by fluctuations in the transfer function and the coherence functions for higher (>50 Hz) frequency range. One can see step-increase in the table motions around 3 Hz in both curves. They can be caused by measurement error for low frequency range of vibration affected by peak of the PSDs at 3Hz, because there is no amplification in transfer function and no change in coherence function for low (<10 Hz) frequency range. Table motions are estimated to be 2 and 6 nm for the two measurements, ignoring the step-increase at 3Hz.

CONCLUSION

We developed the Shintake monitor to measure the focused electron beam size of 37 nm at the IP with resolution of better than 10%. We adopted "Rigid mount on floor", that is individual rigid mounts both for the Shintake monitor and the final focusing magnet in order to stabilize the relative position between the beam and the interference fringes within a few nm. Here, the vertical motions of the table, newly constructed for the Shintake monitor are estimated to be 2 and 6 nm from the two vibration measurements. They are barely tolerant at present; however, we must confirm accuracy of the vibration measurements for low (<10Hz) frequency range.

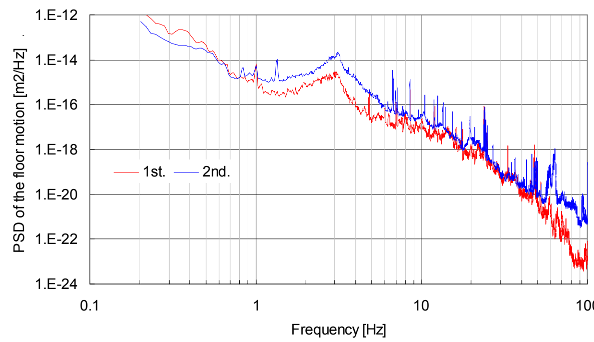

Figure 5: The power spectrum densities (PSDs) of the floor motion obtained from the two measurements.

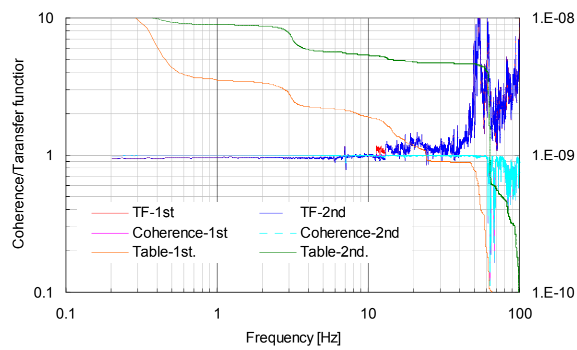

Figure 6: Transfer functions of the table, coherence functions between the floor and table, and table motion relative to the floor obtained from the two measurements.

ACKNOWLEDGMENTS

Authors thank Ryuhei Sugahara and Ryuji Ohkubo of KEK for providing instruments for vibration measurements and also useful advices, Herz co. ltd. for designing and constructing our table based on their excellent knowledge and technique on mechanical stabilization, and researchers and staffs in ATF for encouraging and supporting our studies.

REFERENCES

[1] T. Shintake, Nucl. Inst. Meth. A311, 453 (1992).

[2] B. I. Grishanov et al., ATF2 Collaboration, ATF2 Proposal, KEK Report 2005-2 (2005).

[3] J. Brau et al, International Linear Collider Reference Report, ILCREPORT-2007-001 (2007).

[4] T. Yamanaka et al., Conference Record of IEEE NSS/MIC/RTSD2008, Dresden, Germany, 3308 (2008).

[5] B. Bolzon et al. , "Linear collider final doublet considerations: ATF2 vibration measurements", Proc. PAC2009, Vancouver, Canada, to be published (2009).