ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-MOPHA060

FEASIBILITY STUDY ON MEASUREMENT AND CONTROL OF RELATIVE POSITIONING FOR NANO-BEAM COLLISION

H. Matsunaga#, H. Yoshioka, Takenaka Corp., Otsuka, Inzai 270-1395, Japan
Y. Ohsawa, R. Sugahara, M. Masuzawa, H. Yamaoka, KEK, Oho, Tsukuba 305-0801, Japan

Abstract

A key requirement of the SuperKEKB and future International Linear Collider projects is to measure and control the offset of very small beams with a precision of several nanometers at the interaction point. Using a relative positioning control introduces several technical problems because it is necessary to measure and control short-term vibration and long-term drift between the two distant points. In this paper, we offer a feasibility study for measuring and controlling nano-order relative position by using a laser interferometer and a piezoelectric stage.

INTRODUCTION

The SuperKEKB [1,2] is designed to improve peak luminosity to forty times that of KEKB luminosity and reduce the beam diameter to 60 nm. The beam diameter in the International Linear Collider will be 5 nm. To achieve these nano-beam collisions, it is essential to measure and control a relative offset between the electron and positron beams with a precision of several nanometers.

The electron and positron beam diameters are reduced by superconducting magnets located on both sides of the interaction point. Therefore, the most effective way is to measure and control the relative vertical beam offset at the installation points of superconducting magnets.

Many attempts have been performed to measure the microtremor at accelerator installation sites [3-6], however, those attempts have not been intended to measure relative offsets between two distant points. Kimura [7] proposed a method to measure a relative vertical offset via a water tube tiltmeter, but the method is not appropriate for measurement in the vibration region.

Yamashita [8,9] developed a mover system by using piezoelectric device. The mover can control the vibrations on a table with a precision of approximately 20 nm, however the mover is not designed to measure and control a relative offset between two distant points.

In this paper, we offer a feasibility study for measuring and controlling a nano-order relative position by using a laser interferometer and a piezoelectric stage.

MEASUREMENT ACCURACY OF THE LASER INTERFEROMETER

Experimental Systems

We adopted a laser interferometer (the laser system) of Keysight Technologies, Inc. The optical instruments are summarized in Table 1. The laser system can measure the relative displacement between a linear interferometer and a reflector with nano-order precision. We tested the measurement accuracy of the laser system in the frequency range 1‑100 Hz by using two shaking devices. Our experimental systems are shown in Figs. 1A and 1B.

#matsunaga.hiroki@takenaka.co.jp

Table 1: Optical Instruments

Laser head(C5517)	He-Ne laser: λ =633nm
Linear interferometer(10702A)	Resolution: λ /2
Reflector(10703A)	
Beam splitter(10701A)	15%-split

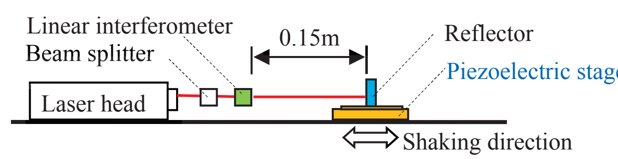

Figure 1A: Experimental system to verify accuracy using a piezoelectric stage.

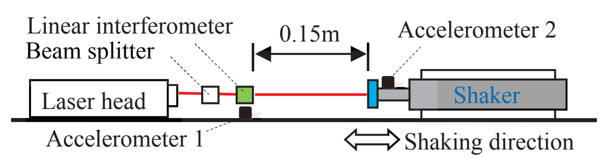

Figure 1B: Experimental system to verify accuracy using a shaker.

Table 2: Specifications of the Piezoelectric Stage

Stroke	200 μ m in XYZ directions
Capacitive type displacement sensor	Resolution of analogue output : 0.4 nm
Resolution in shaking	1 nm under closed-loop control

Figure 1A shows the shaking system by using a piezoelectric stage (the piezo stage) of PI-Japan Co. Ltd. Specifications of the piezo stage are summarized in Table 2. The piezo stage shakes with a precision of 1 nm in the frequency range 1‑10 Hz. The embedded capacitive-type displacement sensor has a resolution of 0.4 nm. We verify the measurement accuracy by comparing the obtained value with the output value of the capacitive sensor when shaking the reflector, as shown in Fig. 1A.

Figure 1B shows the shaking system with a low-frequency shaker of AR Brown Co. Ltd. Two servo-type accelerometers of Tokkyokiki Co. Ltd. are used to estimate the relative displacement by a dual integration

ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-MOPHA060

value of the time history difference between the two accelerometers. One accelerometer is fixed on a movable part of the shaker, and the other accelerometer is placed on the floor at the same position as that of the interferometer. In this system, measurement accuracy is verified in the frequency range 20–100 Hz. Note that a resolution of the relative displacement by using two accelerometers is shown in the next section.

In the two shaking systems, the reflector is fixed on a movable part of the shaking devices. The measurement distance between the interferometer and reflector is set to 0.15 m so that it is not influenced by various disturbances.

Resolution of Accelerometers

The accelerometers are placed on the floor 0.1 m apart in the same horizontal direction and we measured microtremor with a frequency of 1000Hz for a few minutes. Results evaluated in the frequency region using FFT analysis are shown in Figs. 2, and FFT analysis parameters are presented in Table 3.

Figure 2 shows the dual integration value of the Fourier amplitude spectrum of the time history difference between the two accelerometers. The curve is focused to a specific acceleration line of 0.7μm/sec^2. Considering the individual difference of accelerometers and measurement conditions, we conclude that the resolution of the differences between the two accelerometers is in the range of the acceleration line from 0.7 to 1.4 μm /sec^2.

Table 3: FFT Analysis Parameters

Window length	4096 points
Window function	Hanning
Overlap	75%
Averaging	Arithmetic mean

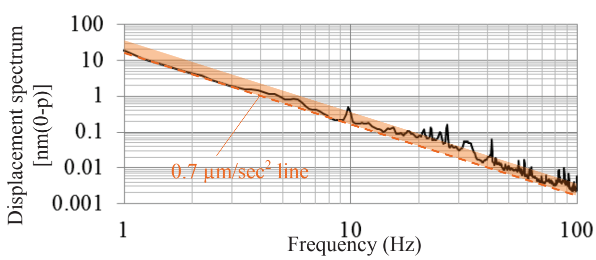

Figure 2: Relative displacement spectrum evaluated by the difference between the two accelerometers.

Verification Results of the Laser Interferometer

The measurement accuracy of the laser system is verified using a sinusoidal shake via the piezo stage or shaker. We performed measurements with a frequency of 256 Hz for 60 s. Sinusoidal frequencies are 1, 2, 3, 5 and 10 Hz in the case of the piezo stage, and are 20, 30, 50, 70 and 100 Hz in the case of the shaker. Measurement accuracy was evaluated in the frequency region by FFT analysis with the parameters shown in Table 3.

The Fourier amplitude spectrum of each measurement device is calculated, a shaking frequency value is detected, and a laser system value is compared with a capacitive sensor or accelerometers value. When comparison error is accurate within 10% based on the capacitive sensor or accelerometers value, a laser system value is evaluated as a measurable relative displacement. Further, the smallest measurable value with respect to each shaking frequency is extracted. Results of our comparisons are shown in Figs. 3. Shaking frequencies are shown along the x-axis and the Fourier amplitude spectrum are shown along the y-axis. We confirmed that the measurement accuracy of the laser system is at least below 2 nm in the frequency range 1–100 Hz.

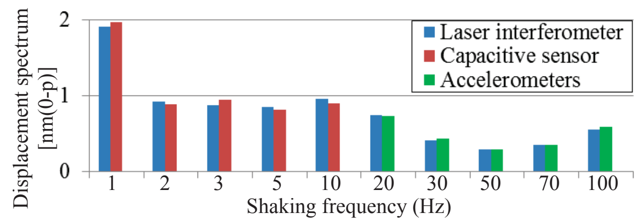

Figure 3: The smallest measurable relative displacement compared with the capacitive sensor or accelerometers.

MEASURING THE RELATIVE DISPLACEMENT BETWEEN TWO DISTANT POINTS

Measurement System

Around the interaction point in the SuperKEKB, we measured the relative displacement between two concrete bridges placed accelerator tubes by using the laser system and accelerometers. The distance between the two concrete bridges is 10 m. Measurement points around the interaction point are shown in Fig. 4.

The laser head, beam splitter and interferometer are placed on one concrete bridge, while the reflector is placed on the other. Moreover, to measure the relative displacements in the X, Y and Z directions, three accelerometers are placed on the two concrete bridges.

The amount of relative displacement for the X, Y and Z directions is estimated on the basis of the differences between the two accelerometers. Furthermore, measurement accuracy of the laser system between two distant points is verified by comparing the obtained value with the difference value between two accelerometers.

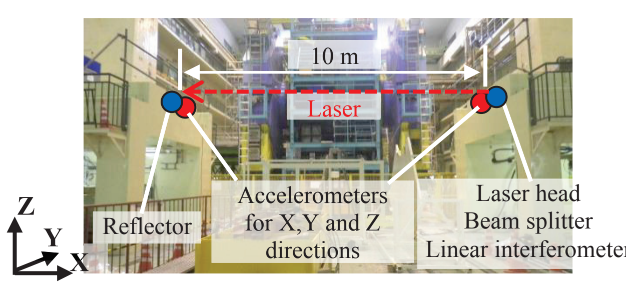

Figure 4:Measurement points around the interaction point in the SuperKEKB.

ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-MOPHA060

Measurement Results

We measured microtremor with a frequency of 1000Hz for 10 min. Results evaluated in the frequency region by FFT analysis with the parameters shown in Table 3 are shown in Figs. 5A and 5B.

The curve of the laser system agrees with the curve of the accelerometers in Fig. 5A. Further, the amount of relative displacement is larger than the resolution of the difference between the two accelerometers in the frequency range 2–100 Hz. Therefore, the laser system is able to measure the relative displacement between two distant points at least in the frequency range 2–100 Hz with a precision of several nanometers.

In Figs. 5A and 5B, peaks occur around 3 Hz. The maximum amount of relative displacement is greater than 30 nm in the Z direction. This value corresponds to approximately half of the beam size in the SuperKEKB.

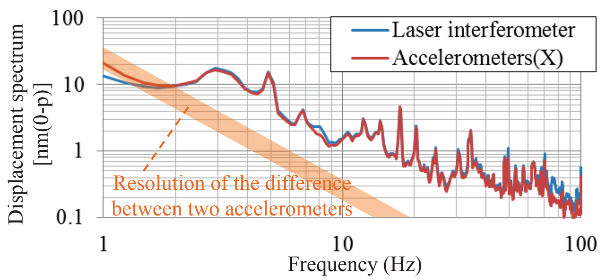

Figure 5A: Relative displacement between two points which are 10 m away along the X direction.

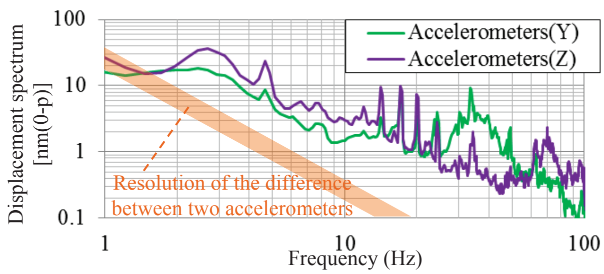

Figure 5B: Relative displacement between two points which are 10 m away along the Y and Z directions.

FEASIBILITY STUDY FOR CONTROLLING RELATIVE POSITION

Experimental System

We tested a relative positioning control by using the laser system and the piezo stage between two distant points. Our experimental system is illustrated in Fig. 6. Optical instruments and the piezo stage are placed on two active vibration isolation tables [10], as shown in Fig. 6. The laser head is fixed tightly on a girder and the reflector is fixed on a movable part of the piezo stage.

The distance between the interferometer and the reflector (line A-B in Fig. 6) is 3 m and this relative displacement is the target of the relative positioning control. Based on the relative position signal between points A and B along the X direction, which is measured by the laser system, we controlled the relative position with PI control by using the piezo stage.

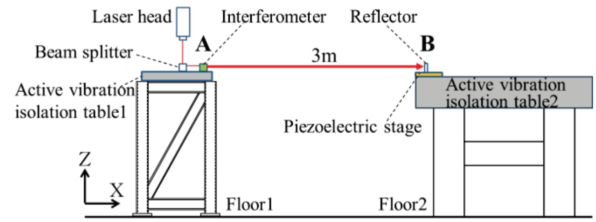

Figure 6: Experimental relative positioning control system.

Results of Relative Displacement Control

We measured the microtremor with and without control cases with a frequency of 1000Hz for a few minutes. Measurement results of the laser system, which are evaluated in the frequency region by FFT analysis with the parameters shown in Table 3, are shown in Fig. 7. Values found at 50 Hz in Figs. 7 are influenced by the electrical noise of commercial power.

The amount of relative displacement without control case is up to several tens of nm in the low frequency region, as with the SuperKEKB. The curve with control case is controlled below 2 nm in the frequency range 1–100 Hz. This result also shows that the measurement precision of the laser system is nearly independent of the measurement distance.

From the above, we conclude that, in principle, it is possible to control the relative displacement between two distant points with a precision of several nanometers.

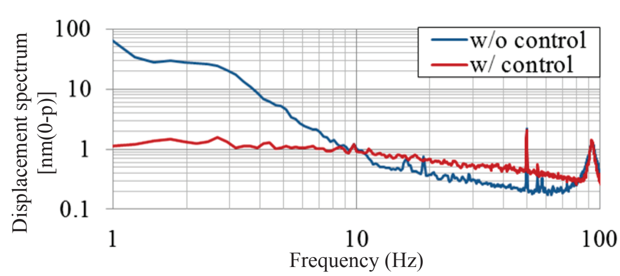

Figure 7: Relative displacement between points A and B, which are 3 m away along the X direction.

CONCLUSION

In this paper, we confirmed that the precision of the measurement position along the direction of the laser radiation is at least below 2 nm in the frequency range less than 100 Hz. Further, we confirmed that the laser system can measure the relative displacement between the two points that are 10 m away with a precision of several nanometers. In addition, we achieved the control of the relative positioning between the two points that are 3 m away below 2 nm in the frequency range less than 10 Hz.

We endeavour to develop technologies to measure and control nano-order relative position along the vertical direction between two distant points in our future studies.

ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-MOPHA060

REFERENCES

[1] K. Oide et al., M03RAI01, Proc. of PAC'09, Vancouver, British Columbia, Canada (2009).

[2] M. Masuzawa, FRXBMH01, Proc. of IPAC'10, Kyoto, Japan (2010).

[3] M. Masuzawa et al., "Vibration issues for SuperKEKB", Proc. of 11th IWAA, DESY, Sep. 11-17, 2010.

[4] M. Masuzawa et al., "Floor level motion observed in the KEKB tunnel", KEK-PREPRINT-2003-97, p. 5 (2003).

[5] R. Sugahara et al., "Ground motion measurement and vibration suppression at KEK", KEK-PREPRINT-2005-77, p. 13 (2005).

[6] S. Matsui., "Floor vibration of accelerator tunnel at XFEL/SPring-8.", Proc. of Particle Accelerator Society Meeting 2009, Ibaraki, Japan, p. 140 (2009).

[7] H. Kimura et al., "Alignment Reference and Subsidence of Floor at XFEL", Proc. of the 7th Annual Meeting of Particle Accelerator Society of Japan, Himeji, p. 4, 2010.

[8] S. Yamashita et al., "Realization of the New System to Control the Vibration in Nano-meter Accuracy for Next Generation High Energy Accelerator", Grants-in-Aid for Scientific Research, Japan, 2004-2006.

[9] Y. Morita, S. Yamashita, M. Masuzawa, R. Sugahara, H. Yamaoka, "Development of a mover having one nanometer precision and 4mm moving range", KEK-PREPRINT-2006-42, p. 11, 2006; Proc. of 9th International Workshop on Accelerator Alignment (IWAA 06), California, USA, TH003, Sept. 2006.

[10] H. Yoshioka, N. Murai, "An Active Microvibration Isolation System," 7th International Workshop on Accelerator Alignment (IWAA2002), SPring-8, Hyogo, Japan, (2002).