A TEST FACILITY OF ACTIVE ALIGNMENT SYSTEM FOR JAPAN LINEAR COLLIDER

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Abstract

A test facility with one control axis has been constructed at KEK to investigate a super-accurate alignment technique for the JLC (Japan Linear Collider) project. The facility consists of a stabilized laser system and a vibration control stage equipped with piezo transducers. Results of the first test show that the distance of about 28 cm is kept stable to 50 nm or better up to the frequency of 20 Hz, against the sine wave disturbance with a 500 nm amplitude.

Introduction

It is a common recognition that a sub-micron alignment system should be developed for the future e+e- collider like the JLC, since the vertical beamsize at the interaction point will have to be as small as 2 nm in order to get enough luminosity. On the other hand, the ground motion of the order of 100 nm should be expected even deep underground. For our information, the ground motion was measured at KEK site for two cases, one on a 16 m deep underground floor and the other at ground level. The results are shown in table 1. The data taken even deeper underground was reported elsewhere.[1] While the high frequency components are easily reduced by the conventional damping method, the lower components below 10 Hz are quite difficult to reduce. This is due to a low specific frequency of the passive vibration-proof table. Fig.1 shows the damping characteristics of the vibration-proof table employed in this experiment. In such a low frequency region, however, we can keep an object stable by means of the feedback method, called the active alignment.

We began a fundamental study last year to understand the control system using a laser interferometer and piezo transducers. The reason why such combination was selected is that the laser interferometer is the most accurate measuring device over long distances, and the piezo transducer seems to be the most convenient tool to move loads of many kg in the range of 10 μm.

In this report we will describe the facility components and the results of test.

Table 1. Ground motion at KEK site.

(a) TRISTAN experimental floor, 16 m underground.

Horizontal (N-S)		Horizontal (E-W)		Vertical	
Amp.(nm)	Freq.(Hz)	Amp.(nm)	Freq.(Hz)	Amp.(nm)	Freq.(Hz)
159	196.0	162	196.0	220	2.5
147	194.0	146	2.5	157	196.0
115	2.5	136	194.0	145	100.0
113	100.0	113	191.5	144	194.0
114	191.5	86	183.5	113	191.5

(b) Assembly hall floor, above ground.

Horizontal (N-S)		Horizontal (E-W)		Vertical	
Amp.(nm)	Freq.(Hz)	Amp.(nm)	Freq.(Hz)	Amp.(nm)	Freq.(Hz)
896	2.5	783	3.0	806	3.5
453	5.5	473	5.0	480	5.0
255	196.0	222	193.5	469	9.5
185	194.0	220	189.5	290	46.5
180	148.0	212	196.0	280	13.5

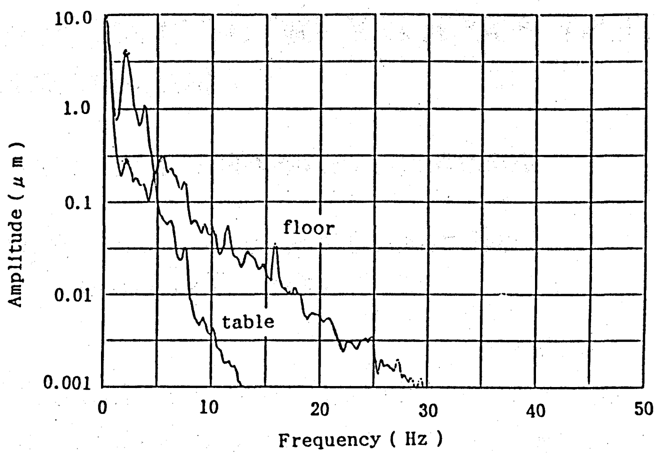


Fig.1 Damping characteristics of the passive vibration-proof table.

Laser system

Since the initial goal of the present test facility is to keep the distance stable as accurately as 50 nm at the maximum length of 1 m, the wave length of laser is required to be stable to 5×10^{-9}. In the near future we will use the facility in vacuum vessels to avoid the effect of air turbulence. With this improvement in mind, we chose the separate-function laser system, called L-IM-10 (He-Ne laser of Tokyo Seimitsu Co.,Ltd.), in which the interferometer head is connected by fiber cables to the laser generator and to the fringe counter. We can easily install the head in the vacuum space by using a feed flange for fiber cables, without any beam alignment. At the present stage, the test has been made in the temperature controlled air of 1 atm.

The principle of the laser system is the Michelson type interferometer as shown in Fig.2.[2] The laser beam coming from the generator is led through the fiber cable to the head and goes to the splitter. One beam goes to the built-in reflector and the other goes to the cornered cubic reflector mounted on the object which we want to measure the distance from. Beams coming back from both reflectors make interference fringes on the plane where four photosensors are arrayed. Each photosensor receives the light intensity given by

$$I(x) = 1 + \cos (4\pi x/\lambda + \alpha),$$

where x is the path difference of two beams, λ the light wave length ($\sim$633 nm) and α the initial phase. The phase difference from the next sensor is $\pi/2$, so the subtracted signals are

$$I_1-I_3 = 2\cos(4\pi x/\lambda) \quad \text{and} \quad I_2-I_4 = -2\sin(4\pi x/\lambda),$$

without dc component.

Since one cycle of the signal is divided into 16, the resolution is $\lambda/32 = 20$ nm.

Piezo transducer and position control stage

The piezo transducer should have low driving voltage to avoide possible discharge in the vacuum space, and to have good linearity to achieve fast response in the feedback system. The selected transducer is Model P-841.20 of Physik Instrumente Co., driving voltage of which is 100 V for the expansion of 30 μ m. The transducer has a position sensor installed in the same casing. It is thereby possible to get as excellent linearity as 0.1 % of full scale.

The control stage made of stainless steel has a double structure, the upper and the lower stage with the same moving axis, as shown in Fig.3. An overall dimension of the stage is 180 mm x 160 mm x 42 mm, and movable parts of both stages have the same dimension of 100 mm x 100 mm and the weight of 1.2 kg. The typical loads of the upper and lower stages are 10 kg and 14 kg, respectively. Since the design value of spring constant is 1.47×10^7 N/m for both stages, the resonant frequencies are calculated to be 193 Hz for the upper stage and 163 Hz for the lower, using the relation

$$f = (1/2\pi) \cdot (K/M)^{1/2},$$

where f is the resonant frequency, K the spring constant and M the load mass. These frequencies are high enough in comparison with the operating frequency of less than 20 Hz.

In order to measure the real motion of the stages, a capacitance microsensor with the accuracy of 2 nm for 1 μ m displacement has been also installed into each stage. Specifications confirmed by our tests are shown in table 2. The discrepancy of resonant frequency between the design value and the actual one is due to the larger spring constant of the actual stage.

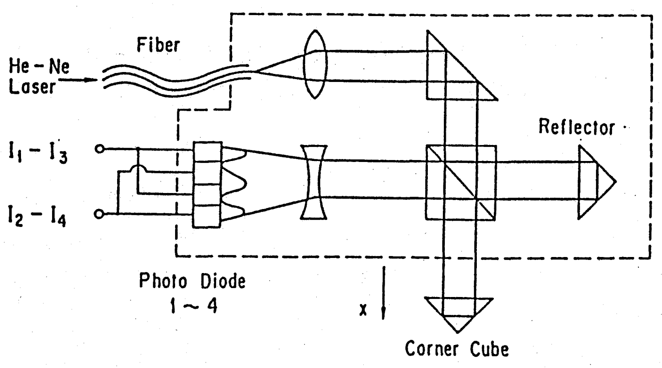


Fig.2 Conceptual drawing of the Michelson type laser interferometer, L-IM-10.

Table 2. Specification of control stage.

Dimension (movable part)	100 mm x 100 mm
Movable range	21 μ m
Yawing	< 0.2 sec
Resonant frequency	250 Hz
Response time	40 msec/μ m
Position resolution	5 nm
Load capacity	20 kg.

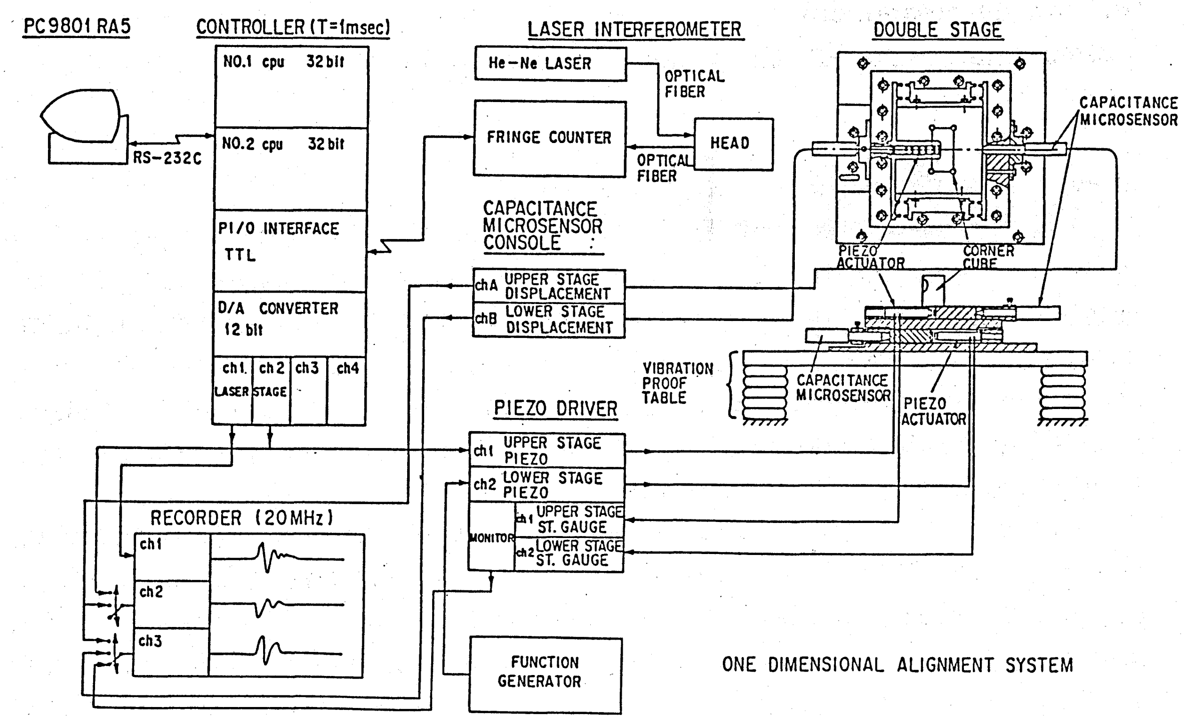


Fig.3 Block diagram of the test facility.

Test

The block diagram of the test facility is shown in Fig.3. The corner cube is mounted on the upper stage and the interferometer head is located 28 cm from the corner cube as shown in Fig.4. The vibration-proof table supports the whole components. The lower stage gives disturbing movements to the upper stage with an arbitrary wave form. The laser system measures the distance between the interferometer head and the corner cube with the sampling time of 1 msec. The CPU of the controller calculates the counteraction required to keep the corner cube stable, and then drives the piezo transducer of upper stage. Results of the test are shown in table 3 and Fig.5 for sine wave vibrations with amplitude of 500 nm. One can see that the damping of 20 db or more is obtained up to 20 Hz. Especially for the vibration of less than 10 Hz, we can keep the stage stable within 30 nm amplitude.

Summary

Our first test has shown that the one dimensional position control system consisting of the laser interferometer and the piezo transducer is able to keep the distance stable around 30 cm with the accuracy of better than 50 nm up to 20 Hz of sine wave vibration of 500 nm amplitude. For tests at longer distances of several m or more, the laser beam path should be evacuated to avoid the variation of refractive index due to air turbulence. Now we are preparing for the test in vacuum. Next step will be the development of the active alignment system having multi control axes.

Table 3. Vibrations after the position control against the disturbance of 500 nm amplitude.

Frequency (Hz)	Amplitude (nm)	Damping (dB)
0.1	19	-28
0.2	18	-29
0.5	19	-28
1	18	-29
2	25	-26
5	27	-25
10	30	-24
20	52	-20
30	77	-16
40	97	-14
50	190	-8.6
60	210	-7.6
70	280	-4.9
80	370	-2.7
90	410	-1.7
100	470	-0.52

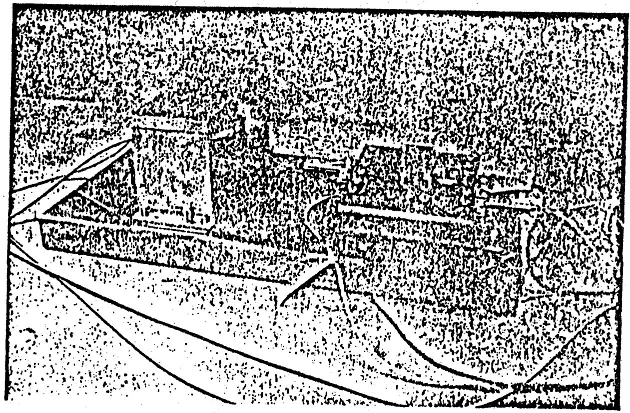
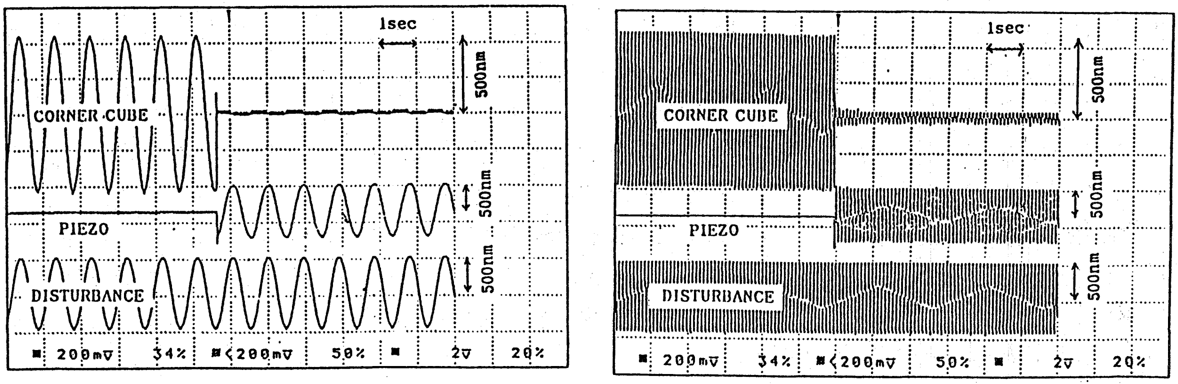


Fig.4 Picture of the test facility.



(a) 1 Hz (b) 10 Hz

Fig.5 Typical damping feature on the oscilloscope. Disturbances of sine wave with 500 nm amplitude are added (a) at 1 Hz and (b) at 10 Hz.

Acknowledgement

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References

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