The Fulfillment of Two-level Control in experimental Optical Delay Line of Michelson Stellar Interferometer

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ABSTRACT

This article is focused on the two-level control system of ODL, which are divided into bottom layer control of linear motor and upper layer control of Piezoelectric Transducer(PZT).This ODL are designed to compensate geometrical optical path difference ,which results from the earth rotation, and other disturbances, with high-accuracy and real time. Based on the PLC of PMAC controller, the linear motor tracks the trajectory of the simulated optical path difference to compensate roughly. PZT then compensates the rest error measured by ZLM almost real time. A detailed fulfillment of this method is shown in the article, and the first result data is produced. The result implies that this method is efficient. This article offers the reference for the ODL development with the practical high accuracy of compensation.

Keywords: Michelson stellar interferometry, optical delay line (ODL), control system, linear motor, PZT

1. INTRODUCTION

Presently, the stellar interferometry has been popularly used in astronomy stellar observation. Beams from two telescopes can be combined in center lab by equalizing the optical path length of both beams. The hard problem to achieve that is to compensate the optical path difference (OPD) between the two telescope arms, which is introduced by the earth rotation and higher order aberrations from environmental condition and mechanical vibrations [1]. Optical Delay Line (ODL) is designed to fulfill the function above. Because the distance between the two telescopes (base line) determines the scale of ODL, ODL is often the outstanding instrument in the whole long base line system. ODL must integrate the optical part, mechanical part and control part together, so it is important to have a global view of the ODL and design it based on the performance of the subsystems of it.

The experimental ODL is showed in figure 1.

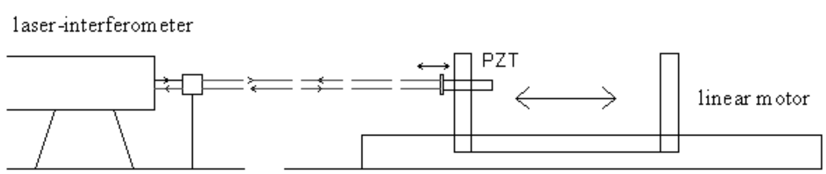

Figure 1. The experimental ODL

In the whole system of ODL showed above, a laser-interferometer is used to measure the actual delay line length, which has a precision of nm. A linear motor is used to compensate the OPD roughly, while a piezo actuator is used for the fine

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control of the ODL. And the command position comes from the simulation OPD trajectory that is produced by a set of parameters.

Figure 2 shows the real scene of our test bed.

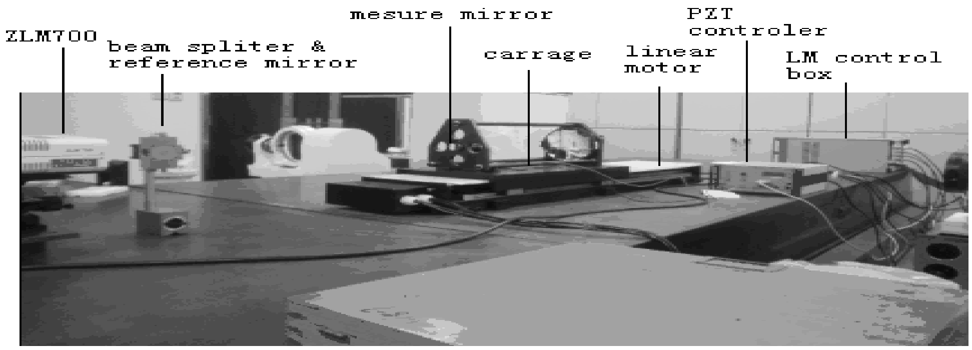

Figure 2.the real test bed of ODL

2. CONTROL SYSTEM DESIGN

In this chapter, firstly a simulation ODL trajectory formula is given. Then the performance of linear motor is tested. After that, a two-level control system of ODL is given out, which refers to control structure of VLTI DL [2].

2.1 Geometrical ODL trajectory

Figure 3 shows the formation of geometrical OPD. Generally speaking, the geometrical OPD depends on the base line length and the angle between base line direction and star light direction, which changes along with the earth rotation.

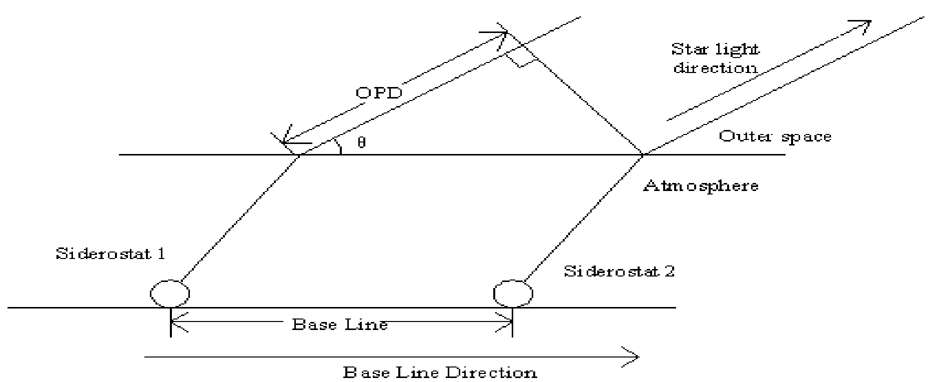

Figure 3. OPD formation diagram

The dependency said above can be expressed with the formula below:

$$L = B \times \cos\theta \tag{1}$$

Where L stands for the length of geometrical OPD,

B for the base line length,

θ for the angle between base line direction and star light direction.

Based on the knowledge of Spherical triangle, we can get the formula of θ :

$$\theta = \arccos[\cos\Phi\cos\delta\cos(\mathrm{H} - \mathrm{T}) + \sin\Phi\sin\delta] \tag{2}$$

which depends on Declination of stellar δ,

Hour angle of stellar T,

Declination of base line Φ (that is the local latitude of the observation),

Hour angle of base line H.

Then the formula (1) can be transformed to formula (3), that is:

$$L = \mathrm{B} \times [\cos\Phi\cos\delta\cos(\mathrm{H} - \mathrm{T}) + \sin\Phi\sin\delta] \tag{3}$$

Because the angle between base line direction and star light direction changes continually along with the earth rotation, we can solve the velocity of ODL. That is:

$$\frac{dL}{dt} = B \times \cos\Phi\cos\delta\sin(H - T)\frac{dT}{dt} \tag{4}$$

In the formula (4) $\frac{dT}{dt}$ is the angular velocity of earth rotation:

$$\omega = \frac{\pi}{43200} \text{ (rad/s)} \tag{5}$$

Also the formula (4) implies that the ODL operates in a changing velocity. So the velocity of ODL should be updated in an enough fast frequency to ensure that the tracking error less than the tolerance error.

We use the Nanjing local latitude 32.061 to replace the symbol Φ,and choose the North-South base line ,so the hour angle of base line is 0,and use the given base line length 10m,we also imagine observing a stellar whose declination is 0 from the zero time. That is:

δ =0,T= ω t, H=0, Φ=32.061,B=10,

So the formula (3) and formula (4) can be transformed as:

$$L = 8.474 \times \cos(\frac{\pi}{43200} \times t)(m) \tag{6}$$

$$\frac{dL}{dt} = -619 \times \sin(\frac{\pi}{43200} \times t)(\mu m / s) \tag{7}$$

Form the formula (6), we can see that if we observation from the zero time point, an ODL length of 8.474m is required. However, our test bed is only 0.4m long. So we should decide whether to observe from a later time, when the required ODL length will shorter than 0.4m, or minus a static value from the original expression of ODL.

If we use the first method, the observation time which our 0.4m long ODL can support is calculated below:

When L=0, t=21600;

When L=0.4, t=20950;

So the observation time between 0m and 0.4m using the formula (6) is:

21600-20950=650s.

The testing time is very short..

If we use the later method that is to minus a static 8.474 from the original expression L then we get the new expression of ODL:

$$L = 8.474 \times \cos(\frac{\pi}{43200} \times t) - 8.474 \quad (8)$$

We can use the new formula（8）to compute the observation time again, that is:

When L=0, then t=0;

When L=-0.4, then t=4241.

It is clear that the later method offer much longer observation time. So we adapt the later method.

Another thing to say is that the new OPD formula doesn't change the velocity formula (7).At last, we use the formula (8) and (7) as the base of simulated geometrical ODL trajectory.

2.2 The performance of linear motor

After aligning the linear motor rail accuracy with the ZLM700 dual frequency laser Interferometer, which is achieved by adjust the compensate table in the Pmac card. Then, the measured length by ZLM well agrees with the Pmac controlled linear motor. In one test, we align a span of 0.4m of the linear motor rail, the aligning results is in table 1below.

Table 1. The alignment of linear motor

Linear motor rail(μm)	ZLM measurement(μm)	Difference(μm)
40000	40000.203	0.203
80000	80000.219	0.219
120000	120001.095	1.095
160000	160000.567	0.567
200000	200001.163	1.163
240000	240001.266	1.266
280000	280001.165	1.165
320000	320002.226	2.226
360000	360001.940	1.940
400000	400002.676	2.676

The Pmac controller offer the PVT mode to control the linear motor .The PVT mode allows user to set the position and velocity of the motor at a given time, so when a series of points in the simulation ODL trajectory is given to the Pmac, then the linear motor will move as the set trajectory.

A PLC of Pmac is programmed and downloaded in the Pmac card, which drive the linear motor move in the simulation geometrical ODL trajectory.

We want to know how well the linear motor can track the trajectory. Through the Pmac own software, we observe the following error item, which shows that the following error will stable about -150cts (1cts=50nm),that is about -7.5μm.

However, when the PLC downloaded in the Pmac card that realized the simulation geometrical ODL trajectory is invoked in the control software through the Pmac dll (dynastic link library), the linear motor doesn't move immediately. So when the invoking time is used as zero time to compute the expected values, we find out that the tracking error of ODL doesn't agrees with linear motor's following error, In fact the two values will go apart very large in long time. The tracking error may behave as the figure 4 shows.

We can see that the tracking error becomes less than -20μm, which is much less than the linear motor following error about -7.5μm. The reason causing this is that the zero time in the control software is not the same as the Pmac starting point. So the expected value of the two will have a larger and larger gap. The measurement is to align our control software zero time to the Pmac zero time.

So we record the m-variables m162 (actual position) and m163 (target position) of Pmac along with the corresponding time, then we can fit out their curve parameter of these two variables in the form of the formula below:

$$L = x(1) \times \cos((t - x(2)) \times x(3)) - x(1) \tag{9}$$

Compared this formula with formula (8), we can find out that an additional parameter x (2), which stands for the zero time offset. This parameter is necessary as the starting time of the linear motor is not easy to get and so the corresponding time may have an offset.

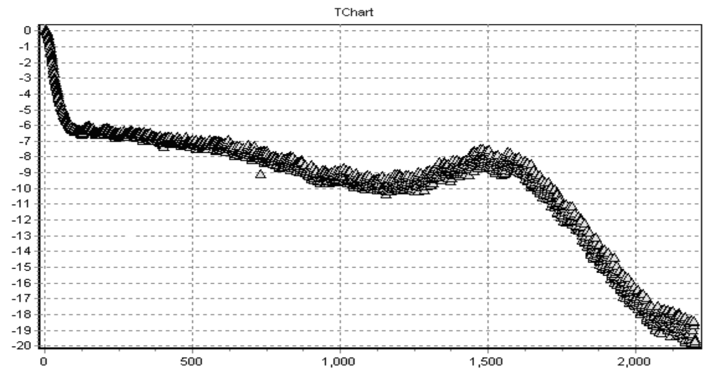

Figure4. Not using the zero time alignment

Using the matlab, we can find out that the m163 fitting parameter fits the formula (8) very well. So we can use the m163 curve to estimate the Pmac zero time. Only if the system zero time is accurate, our expected values computation can make sense and our computation of linear motor tracking error can agree with the Pmac own software. In practice, 50 pairs of m163 and corresponding time are used to estimate the zero time based on the formula (8), and finally the average value is produced.

The figure 5 show the tracking error (between measured position by ZLM and expected position) using the zero time alignment.

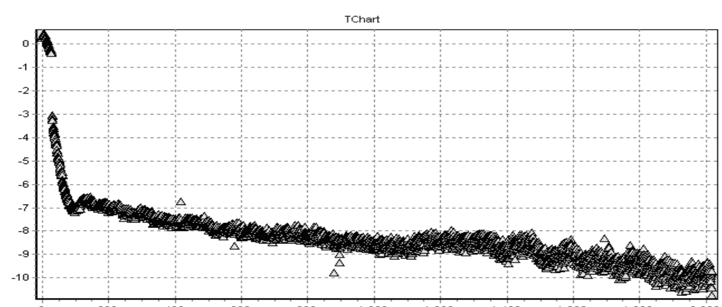

Figure5. Using the zero time alignment

The two figures show that after zero time alignment, the ZLM-measuring tracking error has been much closer to the following error showed by the Pmac own software, which is just the linear motor performance. However the ZLM-measuring tracking error includes the influence on the whole ODL.

2.3 Two-level control

Because the ZLM bus is PXI and the Pmac bus is PCI, it is not easy to integrate the Pmac card and the ZLM card together in the host computer. So we use the Ethernet to communicate the ZLM computer and Pmac computer (main control computer).As the Ethernet data transfer time delay can not be ignored, the control frequency should not be too lager. We use the control logic shown in figure 6.

In the two-level control, linear motor tracks the simulation OPD trajectory to compensate roughly. As the rest error is less than the PZT range, we use the PZT to compensate the rest error. This two-level control work together to enable the whole system error within the OPD tolerance, which we set 0.1 μ m.

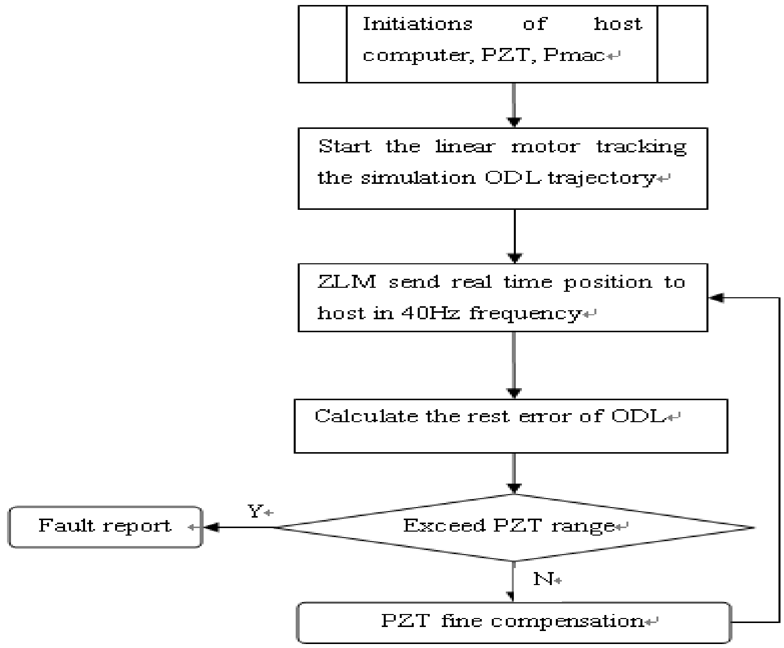

Figure6. Experimental ODL control logic

2.4 Testing result

The tracking error of linear motor can be made up with the PZT movement. We use the control frequency of 40 Hz to test the control system. The result is showed below in figure 7.

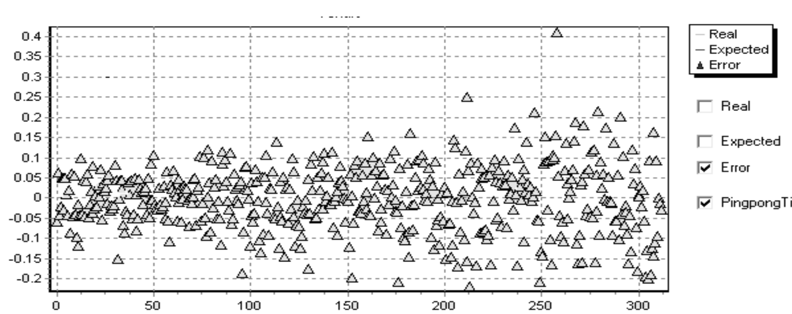

Figure7.the test result of ODL compensating error

The horizontal axis is the time(s) and the vertical axis is the control system error (μ m).The result show that in the first 300s the ODL compensating error is within 0.1 μ m most of time.

3. CONCLUSIONS

Our delay line control system is based on the linear motor rough compensation and PZT fine compensation. In the frequency of 40Hz, it meets the expectation of our experiment. In the future the control system may be improved by adopting hard real time method. It is a choice to make best use of Pmac that support real time multi-task. Then the control frequency can be up to several kHz that meets the need of practical interferometer.

4. ACKNOWLEDGE

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REFERENCES

[1] HarmHogenhuis, Martijn Visser, est. “Test results of the VLTI Delay Line verification program,” Proc. SPIE 4006,198(2000)

[2] Frederic DERIE. “VLTI delay Lines: Design, Development and Performance Requirements,” Proc. SPIE 4006,.26-28(2000)