Optical Delay Line System for the NIAOT Prototype Stellar Interferometer

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ABSTRACT

An optical delay line system for NIAOT Prototype long baseline stellar optical interferometer is being developed. The delay line system consists of optics part, machine part and control part.

The optics part is a cat's-eye system which includes a paraboloidal mirror and a flat mirror. The flat mirror is placed at the focus, and is driven by a piezoelectric actuator for real-time compensation of the tracking error. The defocus of the flat mirror caused by this compensating is considered in optical design; and that the aberration of the optical system design and the manufacture precision of optical components should not cause the decline in visibility of the fringe is analyzed, also.

The machinel part includes precision rails and delay line carriage. The rails require high stability and parallelism. The cart should be quakeproof when it is moved continuously in the observation process, so the rolling friction drive mode is selected as the suitable link method between the carriage and the rails.

The control part includes delay line carriage device control and laser metrology system device control. During an observation, an astrometric model provides a demand cart position and velocity to control computer, the control computer send them to the device controllers. The metrology system produces tracking error fed back to the cart device controller via the control system. This feedback servo loop controls the tracking error.

Keywords: stellar optical interferometry, delay line system, optical path difference

1. INTRODUCTION

Today, the long baseline stellar optical interferometry[1-4] is becoming astronomical observations mainstream technology. More than 10 years ago, the Nanjing Institute of Astronomical optics & technology established a stellar optical interferometry laboratory. Early in 1996, china's first astronomical optical interferometry experimental system [5] (see figure 1) in the laboratory had obtained optical interference fringes, but because of lack of funding and other reasons the Prototype Optical Interferometer did not developed into practical stellar interferometer.

In recent years, NIAOT is supported by the National Natural Science Foundation of China, based on the experimental system, an optical delay line (ODL) system for NIAOT prototype long baseline stellar optical interferometer is being developed at present.

Each interferometer collects starlight by two telescopes then passes the light down an optical train including an optical delay line, finally interferes in a beam combiner. The optical delay line is used to adjust the path length between the two light collection points and a beam combiner in order to equalize the two path lengths. In order to produce interference fringes, the optical delay line system requires compensation optical path differences (OPD) caused by following factors[6-10]:

1) Fixed geometry optical path difference between telescopes at specific position;

2) Diurnal motion of the astronomical objects caused by earth rotation during the observation;

3) Rapid optical path changes along the optical path caused by the atmospheric disturbance and the mechanical vibration.

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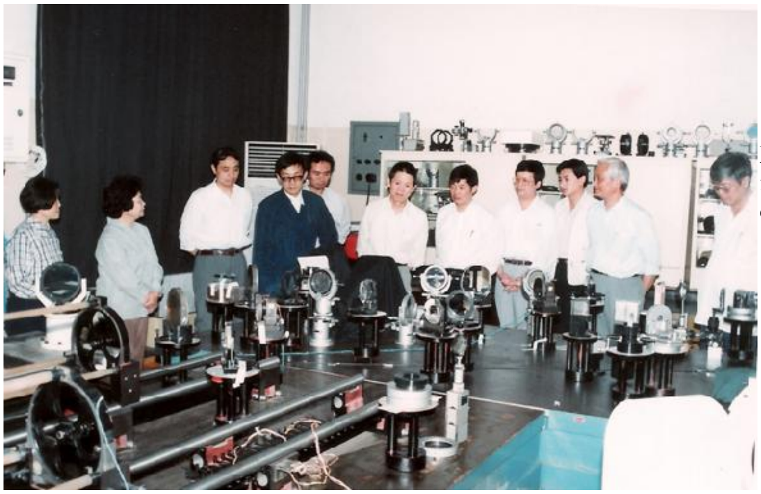

Figure1. Astronomical optical interferometry experimental system of NIAOT in the laboratory

2. SPECIFICATIONS AND PARAMETERS FOR THE OPTICAL DELAY LINE SYSTEM

For an east-west baseline, when the star is at transit, because the angle between the baseline and the incident starlight is 90°, the geometry optical path difference is zero, but its rate of change is approximately 73Bμm/s, where B is the baseline length. For long baselines the delay rate will be very large, and there are practical difficulties in designing a compensating system which can operate at such relatively high speeds. With a north-south baseline, however, the geometry optical path delay rate is zero when the star is at transit[11].

So we are building the following optical delay line system:

1）In order to reduce costs, delay line system is in the air.

2）Choose a north-south baseline, baseline length is 10m.

We wish that we can obtain practical experience for more complex optical delay line system through this building.

2.1 Optical delay line length:

It depends on the baseline length and the zenith distance of the observed objects. For a north-south baseline of length of 10m, the altitude range of observed stars is 60~90°, the maximal delay line length is 5m.

2.2 Compensation accuracy:

If the centre wavelength is 500nm, in order to measure fringe visibility with an accuracy of 1% [12,13] the two interferometer light paths from the star to the beam combiner must be matched to the following optical path differences:

（OPD）=±30μm for an optical bandwidth of 0.5nm.

（OPD）=±3μm for an optical bandwidth of 5nm.

（OPD）=±0.3μm for an optical bandwidth of 50nm.

2.3 Tracking velocity range:

For a south-north baseline, baseline hour angle H=0, and the Nanjing latitude $\phi = 32.061°$, the baseline length B=10m, we have the rate of the OPD:

$$\frac{dL}{dt} = B\cos\phi\cos\delta\sin(H-T)\frac{dT}{dt}$$
$$= -619\times\cos\delta\sin(\omega t)(\mu m/s)$$

In the above expressions, δ is the star declination, T is the star hour angle, ω is the sidereal rate (π radians in 12 hours). The time t varies from 0 to 12 hours (or 43200 seconds). For a star at the declination δ=0, above expressions has maximum:

$$\left|\frac{dL}{dt}\right| = 619\times\sin(\omega t)(\mu m/s)$$

So we obtain the following plot of rate of the OPD vs. time.

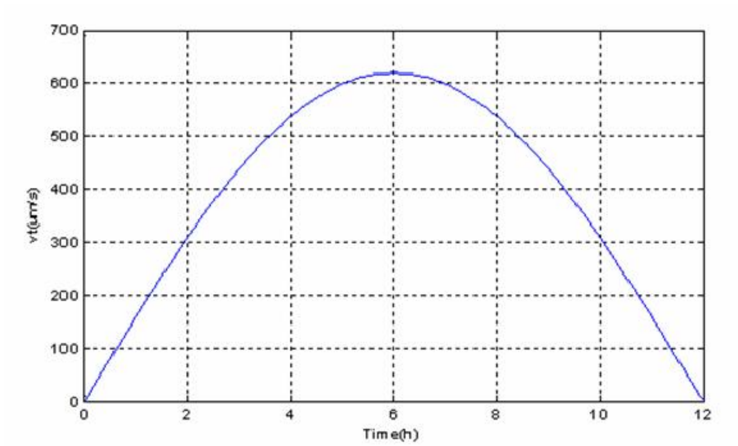

Figure 2 Rate of OPD vs. time for baseline 10m δ=0°

The plot in the graph 2 shows the maximal rate of OPD with the time, the extreme value occurs at t=6 hours. So in the observation mode, maximal tracking velocity of the delay line system is 619μm/s.

Apart from the observation mode, during change of stars, it is required to move the carriage at high speed in order to save time, for a delay length of 5m, for moving the carriage from one end to another end in 5 minutes the maximal slewing velocity is 16.7mm/s at least.

An overview of the main parameters of the optical delay line system is given in table 1.

Table1. Main parameters of the delay line system

Parameter	value
Pressure	In Air
Temperature	Room Temperature
Location	NIAOT, Nanjing, China：lat.32.061 ，long. 118.79125
Baseline	N-S：10m
Delay range	±5m
Tacking velocity	-619μm/s—＋619μm/s
Slewing time Slewing velocity	<5minutes >16.7mm/ s
Wavelength range	Visible spectral range

3. OPTICAL DELAY LINE SYSTEM OVERVIEW

The optical delay line system[16-19] includes different parts, as shown in the figure3.

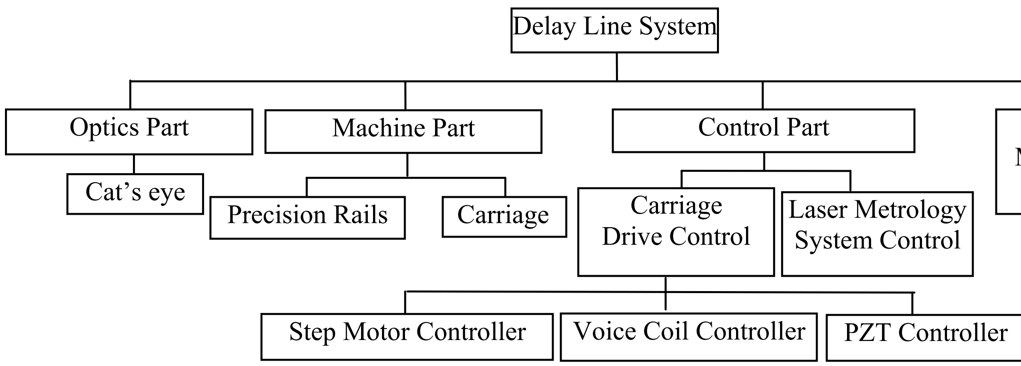

Figure 3 Optical Delay Line system breakdown

3.1 Optics Part

The optics subsystem is a cat's eye retroreflector[19,20], as shown in figure4. The cat's eye is a 130mm f/3 parabola with an 8mm flat mirror at its focus. The defocus of the flat mirror caused by this compensating is considered in optical design; and that the aberration of the optical system design and the manufacture precision of optical components should not cause the decline in visibility of the fringe is analyzed, also. The retroreflector is suspended with flexure arms above a carriage that rolls on steel wheels on the delay-line track.

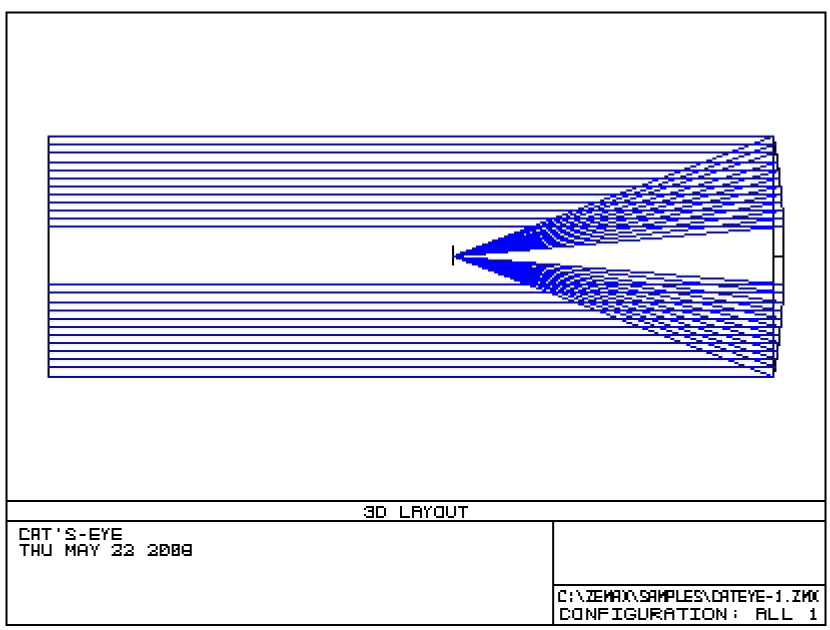

Figure 4 Cat's –eye retroreflector

3.2 Machine Part

The machine subsystem includes precision rails and a carriage. The cat's eye is mounted on the carriage, the carriage rides on 3 wheels. The carriage moves along the precision rails, the precision rails is served for a guiding system of the carriage. The rails require high stability and parallelism. The cart should be quakeproof when it is moved continuously in the observation process, so the rolling friction drive mode is selected as the suitable link method between the carriage and the rails. The position and velocity of the carriage are monitored by laser metrology system.

Starlight enters the retroreflector in a beam parallel to, but above, the axis of the paraboloid, and exits in a parallel beam below the axis. A laser metrology beam also enters the retroreflector to one side of the axis of the paraboloid, exits on the other side, and then returns along the same path. Figure 5shows a schematic diagram of the delay line system.

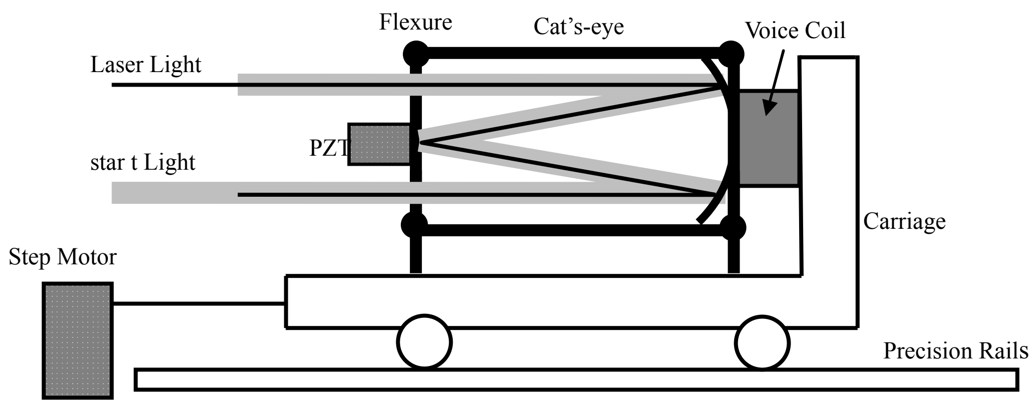

Figure 5 Optical delay line system diagram

3.3 Control Part

The control system (see figure 6) includes carriage control and laser metrology system control. In order to realize the ODL function, the carriage control system uses three nested system and forms a closed-loop control. According to the range of amplitudes and frequency spectrum coved by the optical path differences, the following actuators were considered for ODL control:

1) PZT control, the corresponding frequency response is 500Hz, the dynamic range is ±10μm;

2) Voice Coil control,, the corresponding frequency response is 250Hz, the dynamic range is ±20μm;

3) Stepper Motor control,, the corresponding frequency response is 12Hz.

The control flow in tracking mode is from finest actuator to coarsest actuator, so that each actuator keeps the next actuator centered. Thus the voice coil keeps the PZT within its dynamic range; the stepper motor keeps the voice coil with its dynamic range.

The error signal for control system is the measured optical path difference. The tool for measurement is a 2MHz heterodyne laser metrology system.

The details of the control depend upon the mode of operation: tracking or slewing. Slewing mode is the mode used between observations, in order to implement high-speed point-to-point moves.

The racking mode is the mode used during an observation, where the delay line follows the sidereal and atmospheric motion. During an observation in tracking mode, for given baseline and star position, an astronomical model provides real time control computer with demand carriage position and demand carriage velocity. After receiving these data, the control computer sends the demand carriage velocity on to the carriage controller at the appropriate time. The control computer orders the laser metrology system measures the true carriage position and the true carriage position is fed back to the control computer via the laser metrology controller. The control computer produces error signal to the carriage controller according to the demand carriage position and the true carriage position. The feedback servo loop control the step motor, voice coli and PZT position to minimize the tracking error.

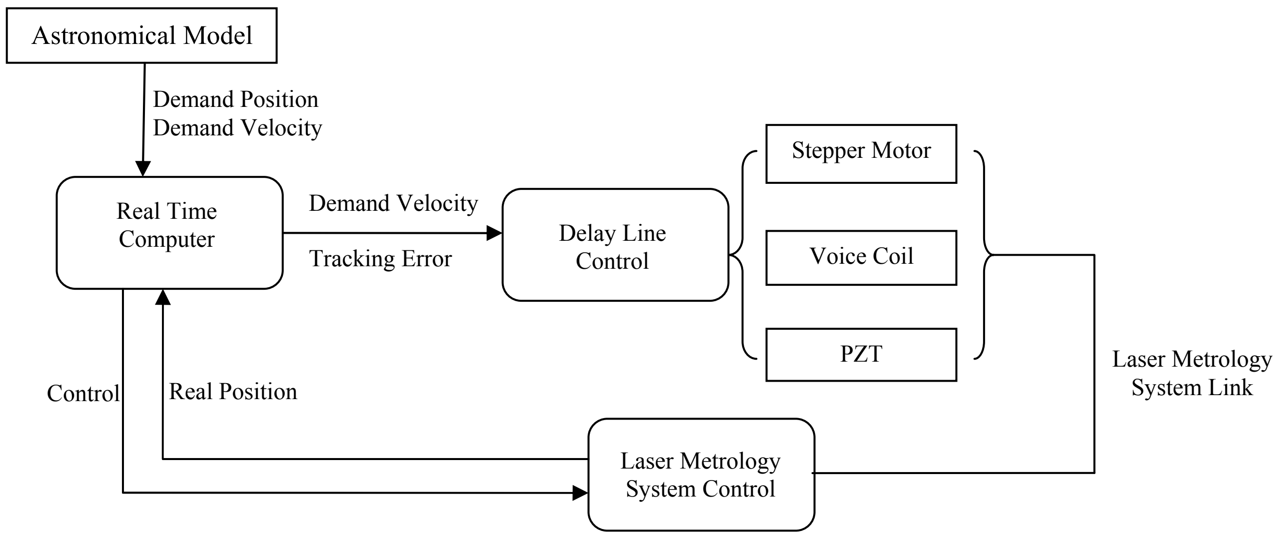

Figure 6 Delay line system control system scheme

4. FUTURE WORK

The optical delay line system is been building in NIAOT, based on this we are going to develop an outdoor prototype stellar interferometer which can be used for the actual observation.

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