The Micro-displacement Worktable Control System of Mirror Detection

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ABSTRACT

This paper mainly introduces hardware design and control method of the system which is used for detecting the M_A segmented mirrors in the LAMOST. According to the demand of sub-aperture stitching interferometer, the system adopts a control card to control the stepping motor to drive the worktable moving on the X-Y. The M_A sub-mirror surface will be changed through active optical correction and add-subtract power of force actuators. The detection result of the M_A segmented mirror of 14 shows that root mean square (RMS) of surface accuracy error is 21.387nm less than 0.035 λ (λ =632.8nm). It is demonstrated that the control system can work very well and shorten the time of detection.

Key words: mirror detection, micro-displacement worktable, control system

1. INTRODUCTION

The traditional way to test optical elements with large apertures is with the support of a large-aperture interferometer. Large-aperture interferometer is expensive, and the technical demand is also strict. The sub-aperture stitching interferometer is a new kind of device that can help to solve this problem. The method of operation of the stitching interferometer is not complex. It consists of measuring a large plane part by part with a small-aperture interferometer and then stitching all the small interferometer together to construct a large-aperture plane [3].

The Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) is a meridian reflecting Schmidt telescope. The telescope is composed of reflecting Schmidt corrector M_A, spherical mirror M_B and focal plane. M_A is pieced together by 24 segmented mirrors. And the segmented mirrors are hexagon whose diagonal length is 1100mm. The mirror-face is flat, but the force actuators on its back will adjust it to the aspheric surface that is needed.

The micro-displacement control worktable of mirror detection is an appropriative platform used for testing the M_A segmented mirrors. The purpose is to accomplish the optical test of all the 24 M_A segmented mirrors. The active optical correction experiment adopts the aperture of 900mm to detect the hexagon thin mirror whose diagonal length is 1100mm. Since the testing aperture is bigger than the collimated beam, 5 apertures parallel piecing together technique is used. Using the datum of the detected mirror from five directions, the large-aperture is pieced together.

2. PRINCIPLE AND METHOD OF STITCHING INTERFEROMETER

2.1 Basic Principle

Figure 1 illustrates the basic theory of stitching interferometer simply. It is to use a small aperture and high precision

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interferometer to measure a part of a large aperture. And each sub-aperture overlaps a bit. In theory the overlapped phase of wave front from two different measuring should be same. And phase information of the two measuring should be on the same level. But the phase may be influenced by inclination and displacement in the test. That is to say the two covers will not be on the same level. Thus, the relative translation, inclination and out of focus of the neighboring sub-apertures' reference covers are worked out with the information from overlapped area, meanwhile all these reference surface of the sub-apertures are standardized in a unique coordinate by working out the relationship among all sub-apertures. So the whole wave plane information can be got.

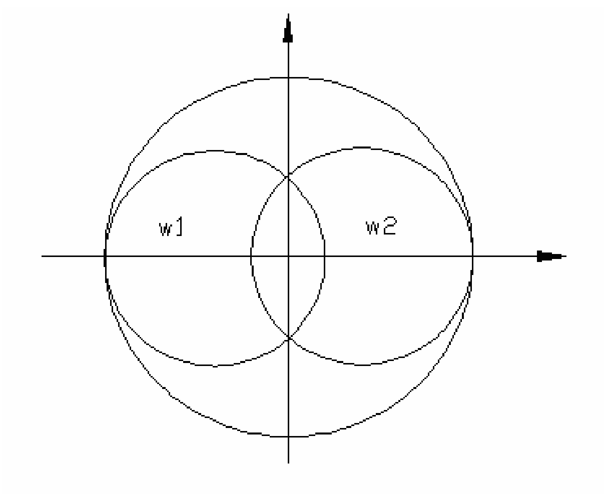

Fig. 1 Principle of Stitching Interferometer

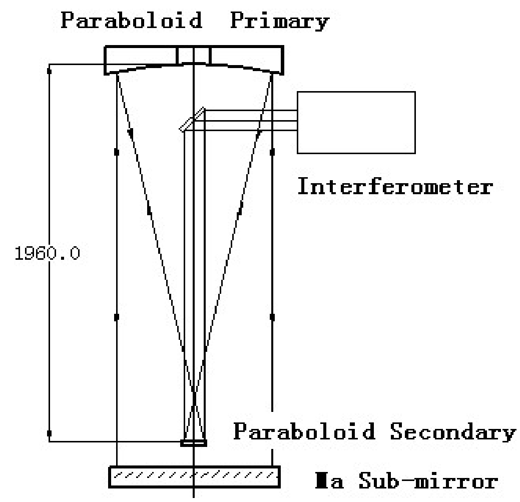

Fig. 2 Optical path of M_A testing

Taking the piecing together of two apertures as example, W_1 and W_2 are the results of two sub-apertures' detection. The phase information of a larger aperture can be obtained by piecing together. If $W_1(x, y)$ and $W_2(x, y)$ are the two apertures' detected phases respectively, they can be written as follows:

$$W_1(x, y) = P_1 + T_{x1} \cdot x + T_{y1} \cdot y + W_0(x, y) \tag{2.1}$$

$$W_2(x, y) = P_2 + T_{x2} \cdot x + T_{y2} \cdot y + W_0(x, y) \tag{2.2}$$

Where $W_0(x, y)$ is the coordinate of the system; P_i is the displacement of the optical axis direction; T_{xi} and T_{yi} are the gradient of X and Y axes respectively.

At the overlapped area in W_1 or W_2, the phase information should be same. So the phase information can be used as a standard to measure the difference between every test and the inclination and the displacement of axis direction of every sub-aperture can be decided. The two formulas can be simplified as follows:

$$\Delta W = \Delta P + \Delta T_x \cdot x + \Delta T_y \cdot y \tag{2.3}$$

$$\Delta P = P_1 - P_2 \ ; \ \Delta T_x = T_{x1} - T_{x2} \ ; \ \Delta T_y = T_{y1} - T_{y2}$$

In theory, three points in different lines are selected in the overlapped area so that the precise value ΔP, ΔT_x and ΔT_y can be got. But there are many errors, so the three numbers can be got through adopting many points and using least square method fitting.

In the process of piecing together, if the surface of big aperture can be covered totally after several times' piecing together sub-aperture and every two piecing together overlap a bit, all the information of the whole aperture can be got.

2.2 Method of Detection

This experiment detects the whole M_A segmented mirrors by using the method of Stitching Interferometer. Figure 2 shows the theory of optical path.

The system adopt the combination of two parabolic mirrors, amplificatory rate is 1:9. The drawtube can turn around the axis which is plumb to the optical axis. The rotational axis gets across the point of intersection between optical axis and coude plane. During the drawtube turning, every angles of the M_A sub-mirror can be detected.

Put the interferometer on one side with adjustment equipment, and adjust optical axis of the interferometer to let it coincide with the turning axis. This can ensure the interferometer place unchanged in the rotation of the drawtube. All the equipments mentioned above should be placed on an appropriative platform which is equipped with quakeproof cushion. The optical system should be scale before detecting M_A sub-mirror.

3. HARDWARE DESIGNING

Stepping motor is the executing element that can transform the signal of pulse into angle displacement. Once receiving a pulse, the rotor will move one step. The motor speed is proportional to pulse frequency. In order to control the mirror detecting platform automatically, the paper adopts the control system. It is composed of an industrial computer, a control card (PCL-839+), tow stepping motor's drivers, two stepping motors and test worktable. Figure 3 is used to show the theory of hardware configuration.

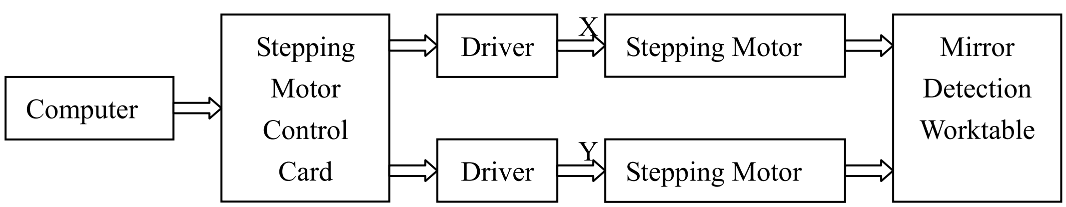

Fig. 3 Theory of Hardware Configuration

3.1 PCL-839+ Features

The PCL-839+ is the core of the whole control system. It is a high-speed three-axis stepping motor control card. It is mainly used to precise X-Y-Z position control and rotation control. Figure 4 shows the general theory of the control. The main characteristics of the control card are as follows:

1) Three-axis control: It uses ISA and can be imported to any PC that owns ISA expansion slot. It has three single-chip pulse generators on-board, which enables the simultaneous and independent control of three axes. The PCL-839+ provides digital pulse and directional control (+and-) for each stepping motor axis.
2) Operating modes: Two-pulse mode (+or-direction) or one-pulse (pulse-direction) mode.

3) Digital I/O: The PCL-839+ features 16 digital inputs and 16 digital outputs for general use (on/off control etc.).
4) Limit switch inputs: The PCL-839+ has five limit switches for additional control of the output. EL+/EL- are the End Limit signal inputs of the right and left. SD+/SD- are the Slow-Down signal inputs of the right and left. ORG is the Origin point input.
5) Movement tracks control: It can realize program trapezoidal and S curvilinear control. It has continuous linear interpolation arithmetic and can update the parameter of the control.
6) Anti-jamming and isolation protection: The PCL-839+PULSE and DIRECTION outputs and limits input switches are isolated from the PC side.

Here only use two in three axes to control X and Y axis's motors in micro-displacement worktable.

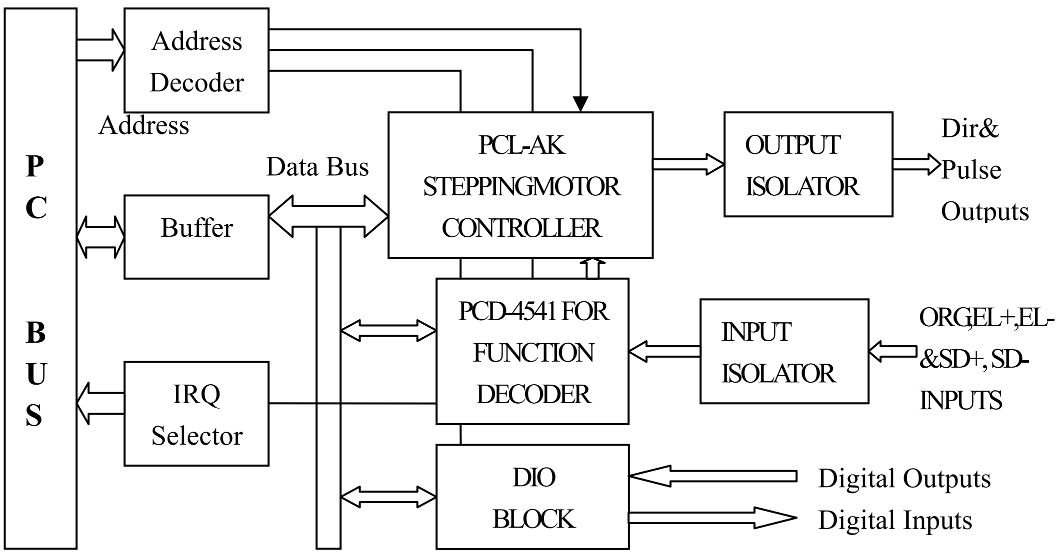

Fig. 4 PCL-839+ 3-Axis Stepping Motor Control Card

3.2 The Designing of PCL-839+ Limit Switches Circuit

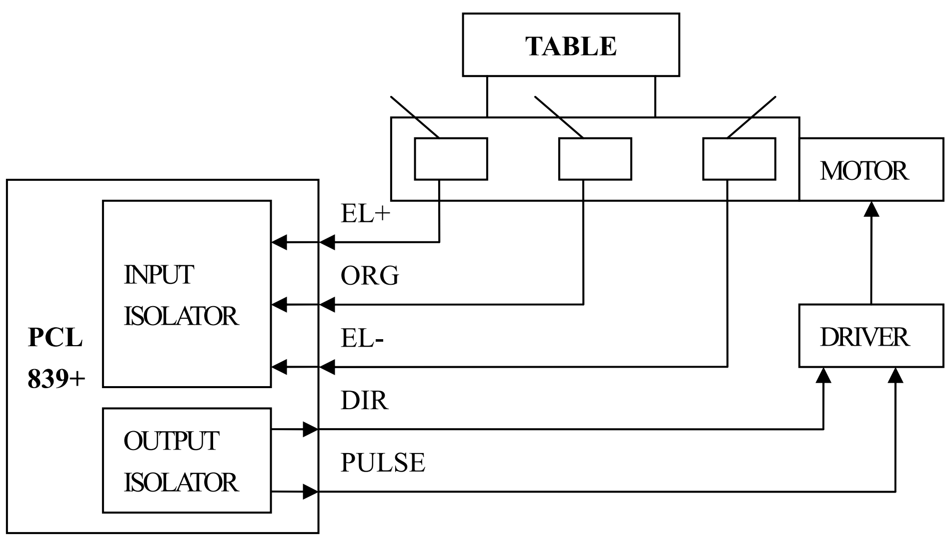

Fig. 5 Using Limit Switches

Although PCL-839+ cater for 5 limit switches, not all of them have to be used in one application. The PCL-839+ can also determine whether the limit switch signal should be normally open or normally closed. On the control platform each main axis uses EL+, EL- and ORG. The limit switches signals are set to normally open, just as the figure 5 shows. EL+ and EL- are installed on the two edges of the table so that the table will not be hurt when moving. Once the table reaches the extremity, a limit switch will be closed and PCI-839+ stops sending pulses preventing table from moving and being damaged. ORG approaching switch is installed in the middle of the table. The worktable moves to the east, south, west, and north four directions from origin when examining. Power supply provides 5V to the limit switches.

3.3 The Designing of PCL-839+ Stepping Motor Drive Circuit

Figure 6 shows the designing of stepping motor drive circuit. PCL-839+ sends pulses and direction (DIR) signals to the stepping motor's drivers, and the stepping motor's drivers drive the stepping motor to turn. The pulse signal is the most important one. Whenever the drivers accept a pulse, it will drive the stepping motor to turn certain angles. Pulse's frequency is proportional to the turning speed of the stepping motor. The turning angles depend on the pulse number. So controlling pulse can locate and adjust the speed of the stepping motor. Direction signal decide the turning direction of motor. When it is one-pulse mode and the signal is the high level, the motor will turn clockwise and vice verse. When they are two-pulse mode, the driver accepts the CW and CCW two pulses. If one (take CW as example) has pulse, the motor will turn clockwise. But if the other one (CCW) has pulse, the motor will turn counterclockwise. Here use one-pulse mode to operate.

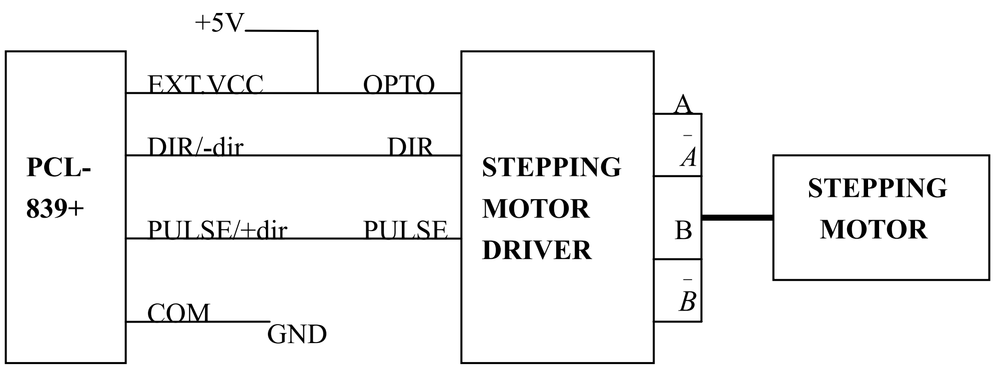

Fig. 6 Stepping Motor Driver Connection

When the order of the moving platform is being carried out, the computer software calculates and puts the pulse, pulse frequency and direction getting from the calculation into the register. PCL-839+ uses the timer on card to fix time precisely. After PCL-839+ analyzing the data in register, it sends pulse to the stepping motor driver according to fixed frequency. The computer checks the sign bit of PCL-839+. When PCL-839+ finishes sending pulses, for there still exists pulse, pulse frequency and direction getting from the former program's calculation in register, it keeps on sending pulses to the stepping motor driver until this instruction is finished. The stepping motor driver drives the motor to turn and drives working platform to move by ball bearing. PCL-839+ can look up limit switch input .So PC can deal with it in time once limit switch signal works. And also there is corresponding sign bit in register to make it easier for a computer to check and read.

4. SOFTWARE DESIGNING

The main work of designing system software is to judge the turning speed, turning direction and location of the stepping motor, to send out a series of controlling pulses according to the sequence and to judge whether the moving equipment reaches the setting point or not.

4.1 The Design on Control of Speed

To locate and control the X and Y axes to move in phase in the control system of micro-displacement worktable, the platform should be moved to the center of X-Y and kept it at the relative origin. And then drive the platform to a certain position by controlling the stepping motor according to the command.

The relationships between the output torque and the frequency of the stepping motor is called torque-frequency characteristic. The characteristic illuminates that the output torque of stepping motor will decrease with frequency rise observably. So it limits the highest frequency and the start frequency of stepping motor. If the start frequency is biggish, losing timing may occur. So it is very important to control the up-and-down speed of stepping motor.

In the control system of stepping motor, once the card sends an order, the stepping motor will turn an angle. If the number of input pulses is N and the output turning angle is θ, then $\theta = KN$ or $\omega = \delta f$ (f is the frequency of drive pulse, δ is pulse equivalent). This is the proportion between input and output. The torque frequency peculiarity curve shows that torque will decline with the speed (frequency) linearly when the turning speed increases. Without considering the damping torque when it starts up, the motor torque can be got by subtracting resistance moment T_L from electrical torque T_0.

$$J\frac{d\omega}{dt} = T_0 - T_L \tag{4.1}$$

When the moment of inertia is invariable, the more load torque is, the less accelerating torque $T_0 - T_L$ is. It is difficult for a motor to start and starting frequency will decrease with the increase of the load torque. If the load is invariable, then electrical torque of the motor will be invariable. If the moment of inertia J increases, then the starting acceleration will slow down and the motor can be operated only when the frequency is low. Electrical torque has to conquer not only the loading torque, but also the inertia torque. When it is started, inertia torque will be less and less and electrical torque just needs to keep balance with the loading torque. So the motor has a process of acceleration to the most track frequency. This is also true for deceleration. So it's important to choose the reasonable speed-curve.

The formula (4.1) represents that the characteristic curve of the stepping motor is exponential. So the exponential curve can give expression to the speed characteristic of stepping motor fully. Analyze the formula (4.1) again. If the resistance moment of stepping motor is $T_L = K_T\omega$ and the accelerating torque is $J\frac{d\omega}{dt}$, then the motion equation of load is acquired.

$$J\frac{d\omega}{dt} = T_0 - K_T\omega \tag{4.2}$$

Where T_0 is electrical torque, J is moment of inertia, K_T is constant of torque, ω is angular velocity. Suppose the speed accelerate from zero ($t = 0$, $\omega = 0$), the solution of the equation (4.2) is

$$\omega = \frac{T_0}{K_T}(1 - e^{-t/\tau}), \tau = \frac{J}{K_T} \tag{4.3}$$

If using the frequency of the drive pulse ($f = \omega / \delta$), the equation can be written as follows:

$$f(t) = f_m(1 - e^{-t/\tau}) \tag{4.4}$$

Here $f_m = T_0 / \delta K_T$ represents the maximal frequency of stepping motor. τ represents time constant of rise and fall-speed which can be get from measure. Equation (4.4) shows f rises with t. That accord with the torque-frequency characteristic of stepping motor [5].

The main task is to design rise and fall-speed of stepping motor. It influences the stability, rise and fall-speed, sound of moving motor, maximal speed and position accuracy. Here exponential curve mode is used. Since the rule of rise and fall speed is the same, the curve takes rise speed for example. The process of speed-up is composed of kick frequency and speed-up curve. Kick frequency is the pulse start-up frequency which is given by stepping motor abruptly in its inactive state. Figure 7 shows the speed-up exponential curve.

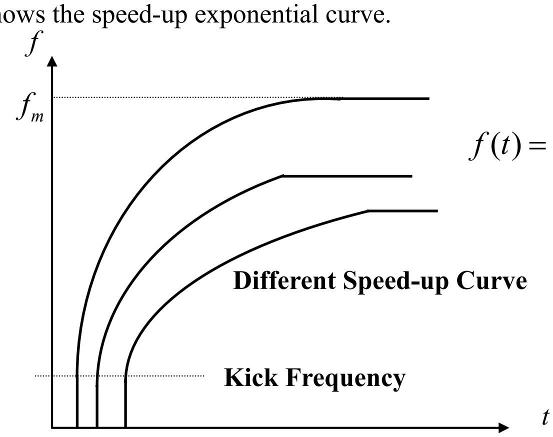

Fig. 7 Speed-up Exponential Curve

4.2 Program and Code

The PCL-839+ has been design to act as a user-friendly solution for stepping motor control applications. 'C' Libraries are provided and they contain all the command functions needed for total control of your stepping motor.

Some codes as follows:

```
int set base(0x300);
int set mode(CH12,DIR);
int set speed(CH12,1000,1000);
int stop(CH12);
int pmove(CH1,P_DIR,FH,40000);
int cmove(CH2,N_DIR,FH);
```

In the process of testing, the worktable can be stopped and moved anytime. Control parameter can be amended when return to the program interface of parameter. The program monitors the limit and stop sign. If these signs are detected, the programs control the card to stop sending pulse, and the stepping motor stop turning.

5. CONCLUSION

In this paper, a computer and the PCL-839+ card are adopted to designing the control system. The stepping motor control card provides powerful function and user-friendly interface, so the worktable can be arrived the appointed position accurately. The control system has worked very well and accomplished the optical test of all the 24 M_A segmented mirrors. The detection result of the M_A segmented mirror of 14 shows that root mean square (RMS) of surface accuracy error is 21.387nm less than 0.035 λ (λ =632.8nm).

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