

# Development of driving and control system of nano-CMM

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**Abstract:** In this paper, the construction of a driving System of Nano-CMM is described. Nano-CMM is a very complex measuring system, which contains complex mechanical structures, precise signal processing, probe system and driving system, and other subsystems and modules. A novel probe, in this system, based on the principle of DVD pickup, is designed for three-dimensional measurement and positioning. Three piezoelectric linear motors are used as the actuators of Nano-CMM. The mechanical structure of working stage here is made specially in order to decrease the Abbe errors. Laser feedback interferometer, a new type of displacement sensor, based on the feedback effect firstly discovered in 1963, is firstly used as position measuring unit. A new driving and controlling strategy of Nano-CMM is proposed, and can be used to achieve the fast and precise driving of large travel with nanometer resolution. The strokes of X, Y, Z are 50mm × 50mm × 50mm, and the stage can achieve nanometer positioning. The time, spent to run the whole stroke in any one direction, is no more than 6 minutes. Currently, the driving system can achieve unilateral rapid and stable approach to an uncertain distance, and effectively prevent the overshoot. And in one dimension, the positioning fluctuations of different distance can be limited in ±4 nm in analogy mode of the piezoelectric linear motor. According to the test results, the driving and control system is suitable for the Nano-CMM.

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## 1. Introduction

Nano-Coordinate Measuring Machine (Nano-CMM) is a necessary tool to measure the dimensions of micro-mechanical parts, such as MEMS parts, micro-gear, etc. Now, several types of Nano-CMM are being developed by famous institutes and universities, such as Technical University of Ilmenau in Germany, PTB in Germany, NPL in England, NIST in America, etc. Since the Nano-CMMs need the measuring accuracy in the order of hundred nano-meter, every part in the Nano-CMM should be designed carefully. The driving system, as one of the important parts of the Nano-CMM, has some special requirements, such as nano-scale resolution, low heat, low vibration and high moving speed, etc[1].

The characteristic of driving system depends on the drive equipments and control strategy. The driving and control system, based on different drive structure, is divided into two categories: one is two-driver system, the first motor is used to accomplish fast motion in a large distance, and the other is used to actuate and position in micro-travel. The other is one-driver system, and only one motor is used to achieve large distance travel and nano-positioning[2]. Two types of driving systems have advantages and disadvantages. Two-

driver system has appropriate characteristics of large travel and fast motion, but its structure is large, and the control is relatively complex and difficult. The one-driver system is expensive, but its structure is smart, and is less difficult to control than two-driver system. And the motion of one-driver system is stable and less fluctuant. In this system, a one-driver system is being adopted.

## 2. Construction of Driving and Control System of Nano-CMM

### 2.1 The structure of Nano-CMM

Nano-CMM is a very complex measuring system, which contains complex mechanical structures, precise signal processing, probe system and driving system, and other modules. The driving and control system is also complex and associates with many parts of Nano-CMM, and is important subsystem of it.

The schematic structure and actual picture of our Nano-CMM is shown as fig.1 and fig.2. In this Nano-CMM, the probe is fixed. The working stage can move in three directions on the drive of the motors in XYZ. The measured object is set on the working stage and moves with the Z stage. The movements of X, Y and Z stages are measured

by three laser feedback interferometers respectively. While the measured object touches the probe, the system records data from the laser interferometers and the probe simultaneously. The measurement results can be obtained after data processing.

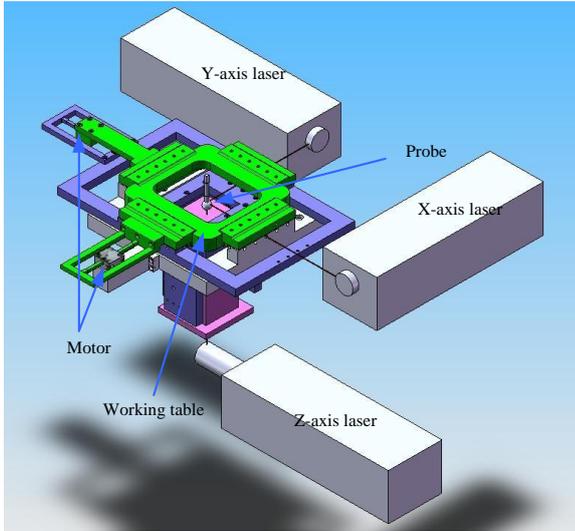


Fig.1 The schematic structure of Nano-CMM

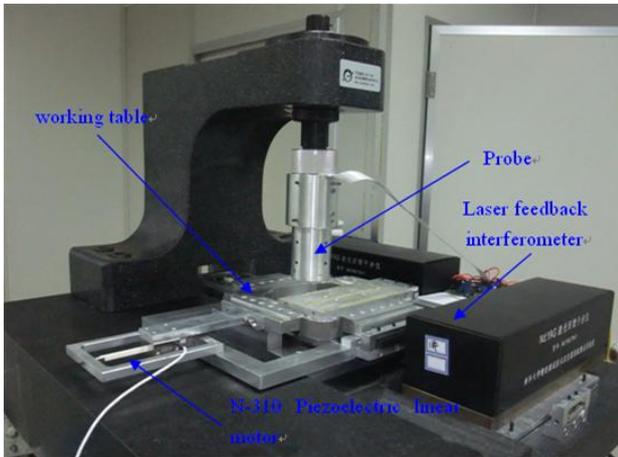


Fig. 2 The photo of Nano-CMM main body

The driving and control system can be as an independent system to achieve large travel and nano-positioning in three-dimensional. The fig.3 shows the frame of the driving and control system.

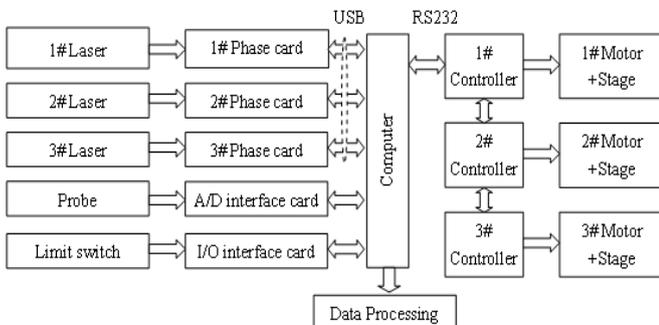


Fig.3 The diagram of driving and control system

In this system, N-310 motor produced by PI company, is used as the driver to achieve large distance travel and nano-positioning. The motor has many advantages, such as small size, high resolution, sub-microsecond dynamic response, self-locking and no wear. Laser feedback interferometer, a new type of displacement sensor, based on the feedback effect, is firstly used as position measuring device. In this system, the probe based on DVD pickup, is used to achieve the

contact measuring. So the driving and control system can be formed with N-310 Piezoelectric linear motor for driving, laser feedback interferometer for displacement measuring, and probe for the feedback control of the nano-CMM.

2.2 Piezoelectric linear motor

In N-310 motor, there are many piezoelectric bodies, assembled into two sides with symmetrical structure, and they have two different motion ways, stretching and bending. Ceramic rod, on the orderly control of piezoelectric bodies, can be driven in two modes, step mode and analog mode.

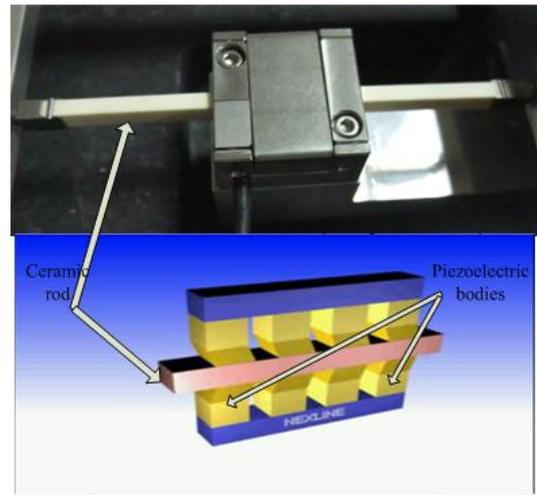


Fig. 4 N-310 motor and inner structure

In stepping mode, N-310 motor can achieve large travel fast and smoothly, and ceramic rod in N-310 motor is driven forward or backward by the orderly movement of piezoelectric bodies. Thrust force supplied by piezoelectric bodies is continuous, and the piezoelectric bodies alternately contact with the ceramic rod.

In analog mode, N-310 motor can achieve the micro-travel actuation and positioning, the piezoelectric bodies are always keep contacting with the ceramic rod. And it can achieve high-dynamics bending motion over a travel range of  $\pm 7 \mu\text{m}$ .

2.3 Laser feedback interferometer

Laser feedback interferometer, a new type of displacement sensor, has wide applications in many areas. It based on the feedback effect [3], firstly discovered in 1963, is firstly used as position measuring unit. The phenomenon of laser feedback is about the changes of the laser power (or intensity) that is reflected by the laser mixing of the reflected light and internal light. The change includes the information of displacement of the reflected mirror. According to the specific relationship between the laser power and the mirror, the displacement of mirror can be measured.

Compared to other laser interferometer, the laser feedback interferometer does not need the prism and the high reflectivity mirror, and it has the advantages of simple and compact structure, easy alignment and low cost, ideally be suited for high-precision measurement of displacement.

2.4 Three-dimensional stage

To ensure accuracy and stability of the control system, the mechanical structure of stage need be designed specially. And the novel stage also can decrease the Abbe errors largely.

The coplanar concept employed in the mechanical design makes the guide planes in x and y in the same height. As a result, the Abbe errors and the cumulative errors can be reduced. The material of the working stage is Invar Steel, for its low thermal expansion coefficient.

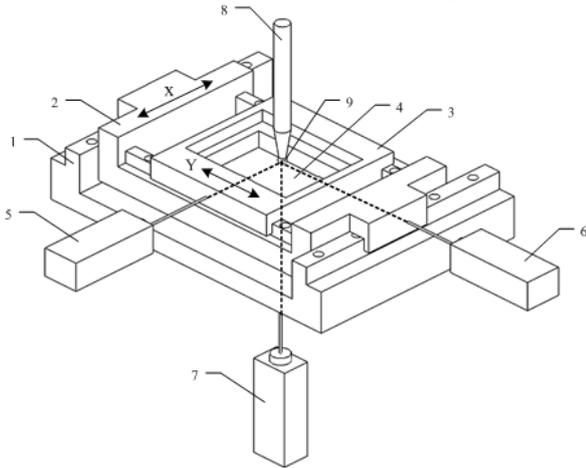


Fig. 5 Diagram of working stage and measurement  
1, X slide; 2, Y slide; 3, the working Slide; 4, Z slide; 5, X Laser feedback interferometer; 6, Y Laser feedback interferometer; 7, Z Laser feedback interferometer; 8, the measuring rod; 9, probe

## 2.5 Probe

The probe, in this system, based on the principle of DVD pickup, is designed for three-dimensional measurement and positioning[1]. The probe position signal can be received by the integrated optical sensor—four-quadrant photo detector. When the probe touches the object, the mirror rotate as a result, and the direction of the reflected light will be changed. Accordingly, the light spot on four-quadrant photo detector will change with the movement of reflected light. A defocus signal will be generated due to the variance of spot distribution at four-quadrant detector. According probe position curve, and the probe displacement can be deduced by the relation of voltage and displacement.

## 3. Control Strategy

Control strategy has a great relationship with the character of motor, and the control algorithm of the driving system needs to be designed according to the actual situation and the requirements of the system[4]. Therefore, the rational design of control algorithm should combine with N-310 motor characteristics, and simplify the control strategy to be implemented easily, while the movement of the motor should not cause damage of the motor itself.

In this system, the conventional PID control has not been used due to the big impact on N-310 motor. Under the control of the PID, N-310 motor will make frequent braking and quick start, and the ceramic rod will be scratched. In the actual controlling process, there are two control modes. One is the step mode that the moving rod can be driven fast in large travel, and the other is the analog mode that the moving rod can be driven slowly but accurately.

In the actual measuring process, the actual location of the measured object is unknown, so we need a position feedback system to sense whether the probe touches the measured object. The probe system can provide the feedback touching information. To make a precise acquisition of probe signal, a two-trigger strategy on the probe

is needed. Since the actual location of the measured object is unknown, at the first time of trigger, the N-310 motor is working in step mode in open-loop, and the velocity of N-310 motor is constant. As soon as the trigger signal of the probe comes first time, the motor pushes back a certain distance immediately and then changes into analog mode. Then the N-310 will move slowly in close-loop. When the probe signal reaches the set value, the motor will remain at the point, and nanometer positioning accuracy can be achieved. The following fig.6 shows the control diagram of close-loop control in analog mode. The purpose of the close-loop in analog mode is to approach the set point in one direction and prevent positioning fluctuation of the set point.

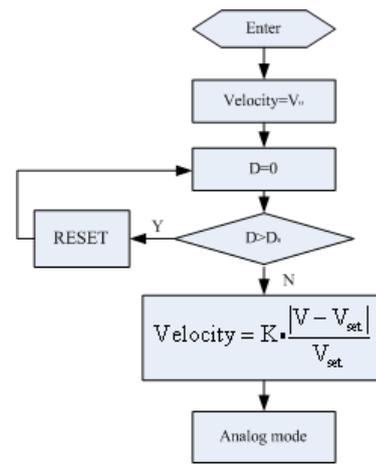


Fig. 6 Diagram of close-loop control

In the fig.6,  $V_0$  is initial velocity;  $D$  is the real-time distance of N-310 motor on analog mode.  $D_0$  is the maximum of  $D$ .  $V$  is the voltage of probe signal, and  $V_{set}$  is the voltage of the fix point of the probe.

## 4. Experiments and Analysis

The driving and control system can achieve nano-positioning accuracy in close-loop on analog mode of N-310 motor. But zero-drift of laser feedback interferometer is inevitable. Thus, although the laser data is very stable, in essence, the motor is constantly adjusting its position to eliminate the fluctuation of laser feedback interferometer. Therefore, the working stage is in vibration, so the stability is a very important issue to the feedback control system.

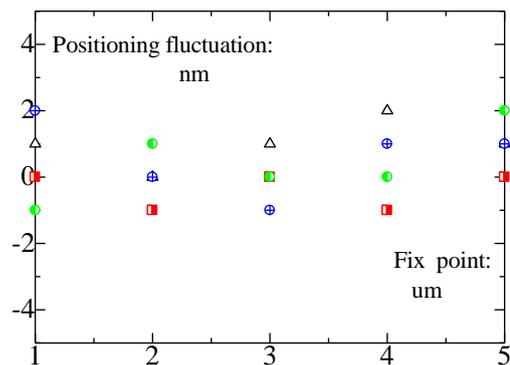


Fig.7 The positioning fluctuation of fix points

Fig.7 illustrates the positioning fluctuations of different fixed

points, and it can be limited in  $\pm 4$  nm in analog mode.

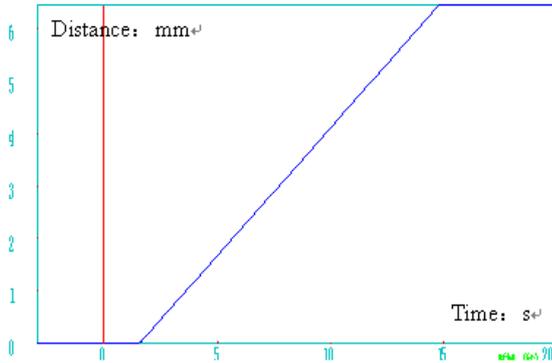


Fig.8 The curve graph of the motion of N-310 in step mode

In step mode, as shown in fig.8, the curve of the motion is very straight. The advantage of the motion in step mode, is driving quickly and improving the efficiency of motion of the working stage.

The instantaneous velocity of the motor in step mode is measured by a Renishaw Laser Interferometer. The signal is shown in fig. 9, in which the velocity is the envelop curve. It can be found from the fig.9 that the fluctuations of the instantaneous velocity of the motor are not great. The velocity of N-310 motor is continuous and constant, the abrupt change of velocity does not occur in the process of motion. The process is continuous, stable and efficient.

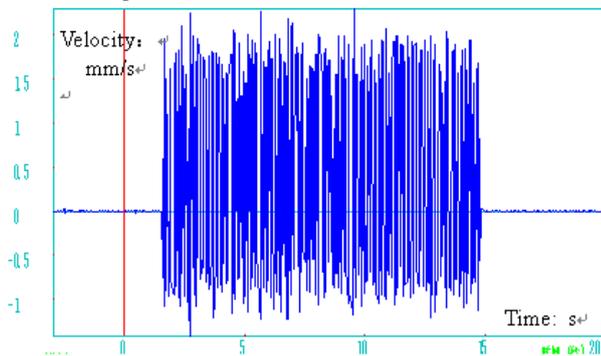


Fig.9 The fluctuations of the instantaneous velocity

In analog mode, all piezoelectric bodies of the motor seize the ceramic rod. On effect of piezoelectric bodies, the motor can achieve ultra-precision motion, but the movement distance is very short. The largest stroke of the motor in analog mode is 7  $\mu$ m. In order to move the rod longer than the stroke, the motor must repeat the analog motion. The fig.10 shows the actual process of the motor motion in a long distance.

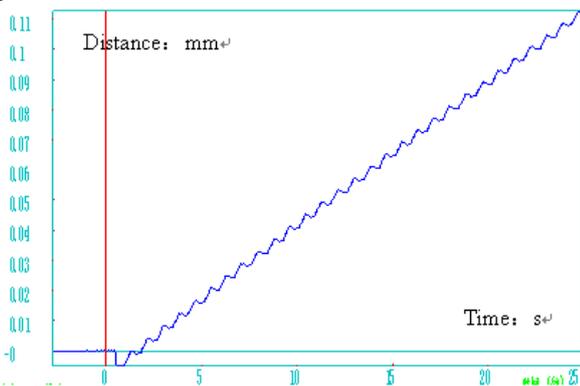


Fig.10 The curve graph of the motion of N-310 in analog mode

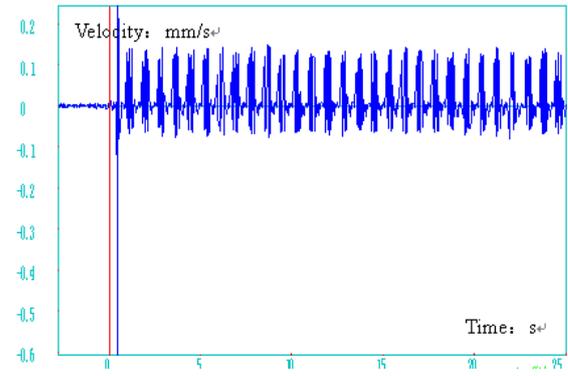


Fig.11 Velocity diagram in analog mode

In the analog mode, the motion of the motor is slower but more stable than in the step mode, the fluctuation of velocity are much more smaller as shown in fig11. So for the motion of nano-precision positioning control, the motor must be controlled in analog mode.

In the actual driving process, the motor need to switch the mode of motor. At the beginning of movement, it's in the step mode for fast driving, and as closing to the target, the mode will be converted to analog mode for precision positioning. The actual mode conversion process is shown as fig.12.

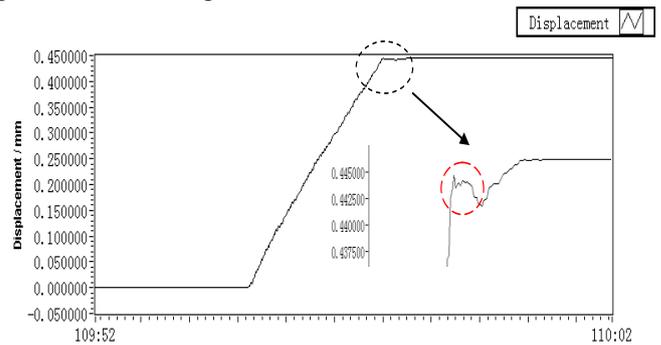


Fig.12 The conversion process of different modes

In black dashed box, it is the actual conversion process of motion control, and evident to find the change of the motor speed. To achieve a precision and fast drive of large stroke, the combination of two modes is necessary.

The red enlarged picture shows that it's need to back a certain distance for the mode conversion. The back is very positive, such as reserving the space for transformation of modes, preventing the random fluctuations in the conversion and protecting the probe system to avoid the strike from the measured object.

#### 4. Conclusions

Nano-CMM is a very complex system of measurement, in which the driving and control system is an important aspect. This research is still in continuing and the present achieved some results. The driving and control system is constructed and realizes nano-positioning in long stroke. In the actual driving process of Nano-CMM, the rapid and stable approaching can be realized to the uncertain distance in one direction, and the overshoot is prevented effectively.

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