Development of High Speed and High Precision Stepping Scanning Platform in Ultra-High Flux Gene Sequencing Imaging System

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Abstract. As a critical component of ultra-high flux gene sequencing imaging system, high speed and high precision stepping scanning platform is used to carrying the gene chips to be measured, and it is also the core component for ensuring the high flux and high accuracy of sequencing instrument. In this paper, taking the high speed and high precision stepping scanning platform in ultra-high flux gene sequencing imaging system as design objective, the research work is carried out from three aspects, i.e., the design of platform overall architecture, the design of dynamic response analysis on system-level structure, and the design of high precision positioning control system, utilizing the optimized design of coupling topology between continuum and discrete body, the high precision vibration test and modal analysis method, variable structure anti-saturation precision control, as well as other key techniques. Finally, a high speed and high precision stepping scanning platform of long-stroke is developed successfully, with stepping speed of 200mm/s, stepping acceleration of 9.8m/s², stable stepping control precision of 150nm, stable stepping duration of 100ms, and the total stepping stroke of 200mm. It lays a solid foundation for the popularization and application of stepping scanning platform in ultra-high gene sequencing instrument.

1. Introduction

The target carrier for measurement of the ultra-high flux gene sequencing imaging system is a measured chip in diameter of 200mm, and the measuring object is a DNB (nanosphere) array at an interval of 600nm and in diameter of 300nm. However, the microscopic objective in the imaging system has a limited imaging field. As a result, the microscopic objective lens should be used in combination with a high performance stepping scanning workbench (6 DOF) for scanning and imaging to ensure the working efficiency of gene sequencing imaging system. High speed and high precision stepping scanning platform is the most important component of the high performance stepping scanning workbench. It works continuously in a stepping scanning mode, which finally realizes the high efficiency imaging of large-area precision details of the chip to be measured.

The stepping scanning platform is used to moving the sequencing chip quickly and accurately on the space two-dimensional DOF X and Y, and to providing ultra-precision positioning control, so that the microscopic objective lens can scan the different field of view in the sequencing chip clearly and accurately. For the accuracy of sequencing, an accurate position of object is required, that is, the accurate correspondence of the relative positions between different fields of view in the process of
stepping scanning, which requires the accurate control of the scanning position, i.e., to ensure that the position stability accuracy of the object is within the allowable range. As a critical sub-system of ultra-high flux gene sequencing imaging system, the high speed and high precision stepping scanning platform is one of the key techniques with urgent need for breakthrough in the product development of ultra-high flux gene sequencing instrument.

2. Composition of stepping scanning platform system

The composition of a stepping scanning platform system is shown in Figure 1, and the X/Y two-dimensional displacement platform shows a laminated motion structure. To improve the rigidity of platform, X-axis displacement platform is guided by cross roller guide at both sides and spherical guide in the middle, driven by double linear motors, and fed back by straight-line grating ruler. While, Y-axis displacement platform is guided by two cross roller guides, and the upper bedplate on Y-axis incorporates the structure of inner trap to lower the center of gravity of the overall platform, which is also beneficial for the overall rigidity of platform.

![Figure 1. Composition of stepping scanning platform structure.](image)

The system modal analysis is carried out with both the X-axis and Y-axis platforms at 100mm of the cantilever, and the resulted first-order modal of stepping scanning motion platform is 438.22HZ.

Stepping scanning motion platform control system mainly comprises of multi-axis controller, low-noise driver, driving motor and position feedback element.

2.1. Multi-axis controller

The high performance workbench control system works under the control of computer. To realize the real-time cooperative scanning motion of X-, Y-, Z-, and Rz-axis, and reduce the delay and cost of control system during multi-axis cooperative motion, a multi-axis controller based on dual-core DSP is designed, with the architecture as shown in Figure 2.

In the multi-axis controller, A/D module completes the high speed and high precision conversion of current signal from motor, and provides the current feedback data to the current loop. The subdivision module subdivides the sine and cosine signal from the grating ruler digitally, and provides the subdivided data back to the control system as the position feedback data of grating ruler. PWM driving module provides SVPWM control signal and directly controls the brushless motor driver for the motor drive [1].

The dual-core DSP performs the control operation, of which each DSP completes the motion control of single axis independently [2]. Accordingly, the multi-axis controller comprises of four DSPs, realizing the cooperative control of X-, Y-, Z- and RZ-axis. All DSPs share the data through FPGA to realize multi-axis real-time cooperative control. Among different cores of DSP, DSP-Core 1 performs control algorithm operation and external interface data collection, DSP-Core 2 performs motion trajectory generation and data sharing management among DSPs. In addition, the master DSP of multi-axis controller extends the Ethernet interface to receive working mode instructions and working parameters from the upper monitor through Ethernet, and at the same time to upload the working data and its own state data collected by the controller in real time.
2.2. **Multi-axis controller**

To drive the brushless DC motor, the low-noise driver adopts three-phase PWM bridge drive mode, as shown in Figure 3.

![Multi-axis controller diagram](image)

**Figure 2.** Architecture of multi-axis controller.

The phase current of Hall sensor induction motor with high linearity and high precision is used in the driver, and the Hall signals are connected to the multi-axis controller through the operational amplifier. The three-phase PWM signal output by the controller controls the on/off of high-speed IGBT through the IGBT driver. DC voltage is chopped into the phase voltage with different pulse widths. Under the inductance of motor, the three-phase current of A, B and C is approximately a sinusoidal waveform with phase difference of 120°.

2.3. **Driving motor**

The two motion axes of high speed and high precision stepping scanning motion platform are driven directly by high performance motor. X-axis and Y-axis are driven by slotless brushless linear motor, with very low torque fluctuation characteristics, which is helpful to improve the steady-state accuracy of scanning motion. Both X-axis and Y-axis are operated under synchronous dual-motor drive to improve the acceleration ability of X- and Y-axis. X-axis and Y-axis motors are BLMC 192-A-ACC motor from Aerotech.

2.4. **Position feedback element**

The position feedback element of the X-axis and Y-axis motion is an incremental linear grating ruler of type RELM-A-9600-280.
An analog signal output reading head is attached to the X-axis and Y-axis linear grating ruler. A positive cosine cycle signal is output every 20um of grating distance, which is equally subdivided digitally into 8192 parts. By this way, the position feedback data with the position resolution of 2.44nm can be obtained.

3. Type design of high speed and high precision positioning control structure

The gene sequencing instrument scans the sequencing chip in a stepping mode. The control system faces the problems of short duration, high acceleration/deceleration, high precision positioning and complex control [3]. On the basis of self-developed low-noise multi-axis control driver, the control program of X-axis and Y-axis scanning workbench has been prepared and commissioned.

The control system adopts a three-loop control structure, as shown in Figure 4, i.e., the current loop, the speed loop, and the position loop from the inside out, and the bandwidth is reduced gradually in the same order. The current loop acts to make the current response faster and more stable, the speed loop stabilizes the speed of follow-up object, and the outermost position loop functions to track the position stably. A feedforward controller, as auxiliary control, is provided on the basis of closed-loop control system. As the closed-loop system is corrected by error, the lag is unavoidable, and in such case, the feedforward controller can correct the system ahead of time. The closer the feedforward controller is to the inverse of the controlled object, the more accurate the advance correction to the system is.

![Figure 4. Block diagram of precision scanning workbench control system.](image)

The accelerated/decelerated stepping motion of motor in a short time will excite the high frequency vibration of workbench, and in case that these high frequency vibrations are outside the suppression range of control system, the subsequent quick stability of high precision is rather difficult [4]. In addition, under the interaction of forces, the motor stepping will also bring impact to the base, and accordingly cause the jitter of sequencing platform when the energy and frequency of impact reach the resonance point of the base [5]. Therefore, during stepping control, the stepping trajectory will be optimized to avoid unnecessary vibration, depending on the characteristics of control system and the vibration characteristics of sequencing platform.

In case of single control, during the acceleration/deceleration and the stabilization of workbench, the control system always adjusts control amount continuously in respect of the errors to approximate a given stepping trajectory, which will additionally increase the control amount of high frequency, and make against the stability of workbench [6]. In fact, the workbench has different control targets in the stepping scanning. At the acceleration/deceleration stage, the control target is to control the workbench to move to a specified destination area following the stepping trajectory in a specified period, allowing a low position accuracy; while at the stabilization stage, the control target is to control the workbench to keep stable at a specified position, requiring a high position stabilization precision. By the variable-structure control mode, the more optimal control performance will be achieved by adjusting the control mode, parameters and control state variables depending on the control target at different stepping stages.
4. Conclusion
The stepping progress, control stability duration and control stability precision of X-axis and Y-axis platforms are better than the specifications for high-speed and high-precision stepping scanning platform in ultra-high flux gene sequencing imaging system. The stepping progress time of X-axis is less than 100ms, the stepping progress time of Y-axis is less than 50ms. And the control stability precision of X-axis is better than 100nm, the control stability precision of Y-axis is better than 60nm.

5. References
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