

Design of loading test bench for precision ball screw based on LabVIEW+PXI

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Abstract. In order to discuss the dynamic characteristics of the aerospace ball screw pair, the paper designs a loading test bench based on Labview+PXI platform and magnetic powder brake. The test bench can simulate the loading condition up to 10Hz. In structural design, magnetic powder brake is used to apply the loading force. In hardware design, the system is built by using upper-lower computer system architecture based on PXI bus. In software design, the program is written in LabVIEW, which mainly includes the data processing and display program in the upper computer and the data acquisition program, the motor control program in the lower computer (PXI). Finally, the test bench was built and the inertia loading test and the rated speed loading test were carried out. The test results verify the effectiveness of the high-frequency loading measurement and control system, and provide a reliable test platform for the dynamic characteristics of the ball screw pair under high-frequency conditions.

1. Introduction

The application of ball screw pair in aerospace servo control system is more and more extensive. It often appears stuck phenomenon in aerospace high frequency working condition, which damages the ball screw pair [1]. Therefore, considering the complex working conditions of the ball screw pair, it is necessary to design a ball screw pair high-frequency loading test bench, which can effectively simulate the actual working conditions and obtain more realistic test results. It is beneficial to the research and performance improvement of the dynamic characteristics of the ball screw pair under high frequency conditions.

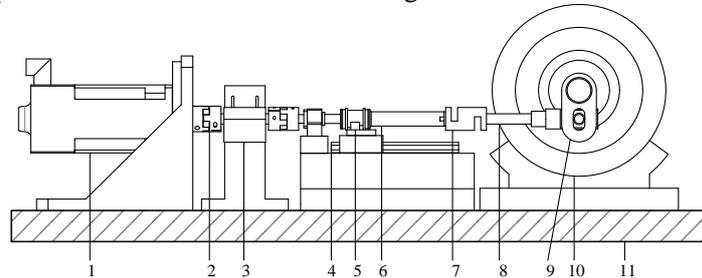
In the research on the dynamic characteristics of the ball screw pair, Shen Xiaoyan[2] explored the influence of high speed on the dynamic characteristics of the whole screw pair through theoretical analysis; Ma Hongjun[3] designed a precision retention loading test bench and its measurement and control system for ball screw pair; Chen Manlong[4] designed the ball screw pair dynamic loading test bench and designed the measurement and control system with LabVIEW software.; Garinei[5] designed a non-contact measurement test bench that uses a Hall sensor to acquire signals ,so as to test the dynamic characteristics of ball screw.

The permanent magnet synchronous motor (PMSM) is used as the motion control unit, the magnetic powder brake is used as the loading unit, and the hardware is built based on PXI platform. In the program design, LabVIEW is used to write the upper-lower computer program. Finally, the effectiveness of the test bench is verified by inertial force loading test and axial constant force loading test.



2. Structure principle

The structural principle of the test bench is shown in Fig.1.



1-permanent magnet synchronous motor; 2-coupling; 3-torque speed sensor; 4-linear guide; 5-acceleration sensor; 6-ball screw pair; 7-pull pressure sensor; 8-Push rod; 9-rocker arm; 10-magnetic powder brake; 11- pedestal

Fig.1 The structural principle of the test bench

In the test bench, the ball screw nut and the sleeve are integrated, and the nut sleeve is connected to the force sensor through a bolt. The input end of the torque and speed sensor is connected with the driving motor, and the output end is connected with the input shaft end of the lead screw through the coupling. The acceleration sensor is fixed on the nut reverser side. The push rod slides in the rocker arm groove, and the rocker arm is connected with the magnetic powder brake shaft end[6]. When the ball screw pair under test moves back and forth, the push rod and rocker arm drive the magnetic powder brake shaft end to rotate.

3. Hardware structure

In order to obtain a high-precision control system, it is necessary to build a reasonable and efficient hardware architecture based on the structure and principle of the ball screw pair high-frequency loading test bench. According to the theoretical analysis, the hardware architecture of the high-frequency loading test bench is shown in Fig.2.

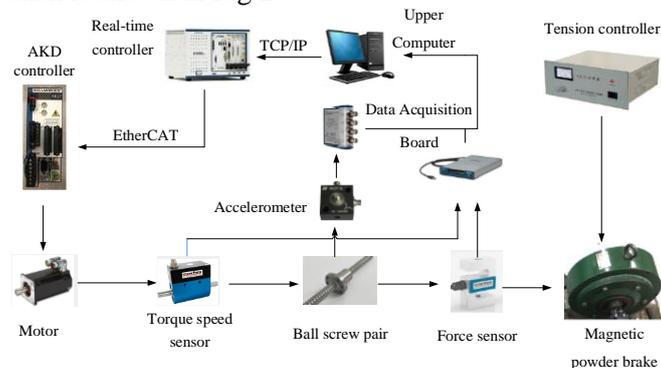


Fig.2 Hardware architecture of the test bench

The system workflow is as follows. First, the upper computer transmits the command to the real-time controller through TCP / IP protocol, and then the controller transmits the command to the motor driver through EtherCAT protocol, so as to realize the control of the motor. Second, torque speed sensor, force sensor and acceleration sensor transmit the data, which has been collected, to the upper computer through data acquisition card. Finally, control the loading force of magnetic powder brake by tension controller.

In the selection of hardware, the NI PXIe-8840RT real-time controller of National Instrument Company is selected and inserted into the NI PXIe-1071 case. Then, in order to collect the data signals of speed torque sensor and tension pressure sensor, the NI PXI-8231 Ethernet card and NI USB-6351 data acquisition card are inserted into the corresponding card slot of the case. At the same time, NI

USB-9234 dynamic acquisition module is selected to collect the data signal of acceleration sensor. The model of magnetic powder brake controller is WLK-5A[7].

In the selection of test bench components, the drive motor is the AKM53H-ACCNR-00 Kollmorgen servo motor and the motor driver model is AKD-P01206; the CZ-30 magnetic powder brake is selected[8]; The total length of the ball screw pair under test is 232 mm; The torque speed sensor of Interface T3 model and the tension sensor of Interface SSM type are selected. Finally, the piezoelectric accelerometer of DH311E model is selected.

4. Software structure

4.1 Architecture of software

After completing the hardware structure design of the loading test bench, the control structure of the software is designed. According to the design principle of LabVIEW software, the software architecture of the system is designed on the PC based on LabVIEW platform. The specific software architecture is shown in Fig.3.

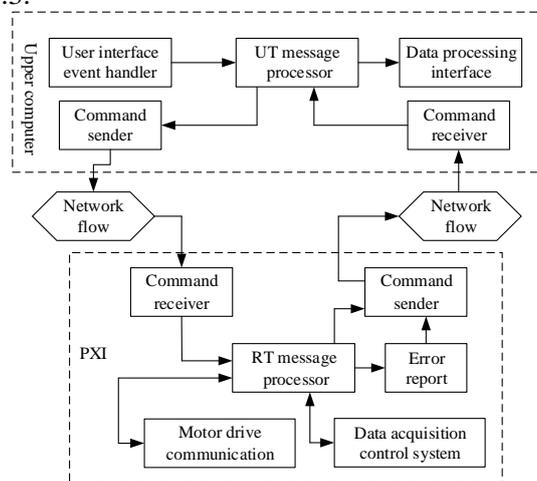


Fig.3 Control structure of software

The main program can be divided into upper and lower computers. The upper computer program (non-real-time program) is mainly responsible for the selection of test items, data acceptance and storage of the lower computer, graphic display, control command transmission and so on; Lower computer program (real-time program) is mainly responsible for sensors data acquisition, configuration analysis of the upper computer commands and real-time control of the servo motor; TCP/IP network protocol is used for communication between the upper and lower computers.

4.2 Upper computer

The upper computer program part mainly realizes the data acceptance of the lower computer, the processing of the software interface and the display of the human-computer interface. The program is divided into three parts: event processing loop, UI message loop, and data receiving loop. Each part of the loop program transmits message and data through the message queue. The event processing part is mainly responsible for selection of test items and generation of control instructions; The UI message loop part is mainly responsible for data processing and display; The data receiving loop part mainly receives the data packet sent by the PXI lower computer in real time. The program architecture is shown in Fig.4.

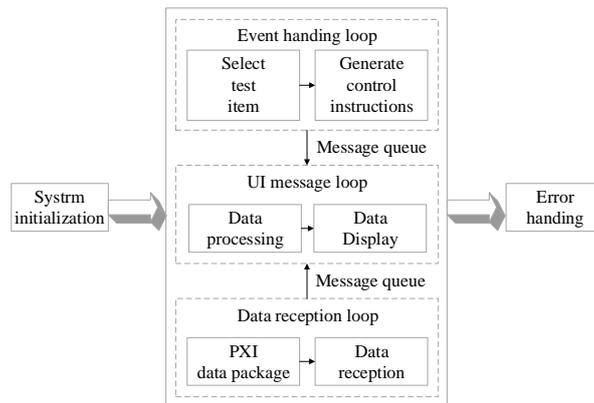


Fig.4 Upper computer program architecture

The loading test of ball screw pair needs to collect the signals of axial force, acceleration and motor torque. The three signals are collected and transmitted to the upper computer for display through the data acquisition program at the same time. The software operation interface is required to realize the function of data acquisition start and end as well as saving. The software acquisition interface is shown in Fig.5.

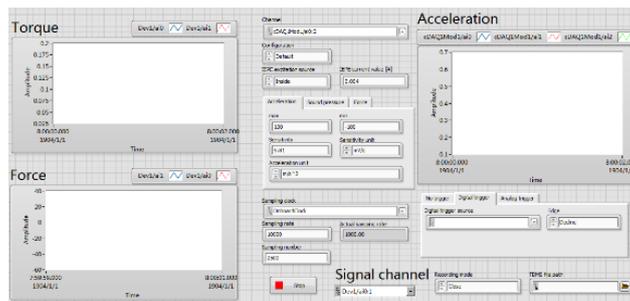


Fig.5 The software acquisition interface

4.3 Lower computer

The lower computer program (real-time program) is mainly responsible for sensor data acquisition, configuration analysis of the host computer command and real-time control of the servo motor.

4.3.1 PMSM Control Module

The loading test bench converts the rotational motion of the PMSM into a linear motion of the screw pair through the ball screw pair. The PMSM model is relatively mature, its vector control block diagram [9] is shown in Fig.6.

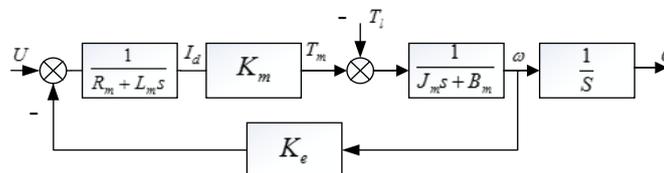


Fig.6 PMSM control block diagram

Where U is the input voltage; K_e is back electromotive force constant; J_m is the rotary inertia of the PMSM; B_m is the damping coefficient; T_i is the output torque of PMSM; ω is the angular velocity of the PMSM; T_m is the electromagnetic torque of PMSM.

The control program part of the drive motor is a key part of the real-time control program, which is controlled by the EtherCAT communication protocol to control the PMSM. The motor control program is shown in Fig.7.

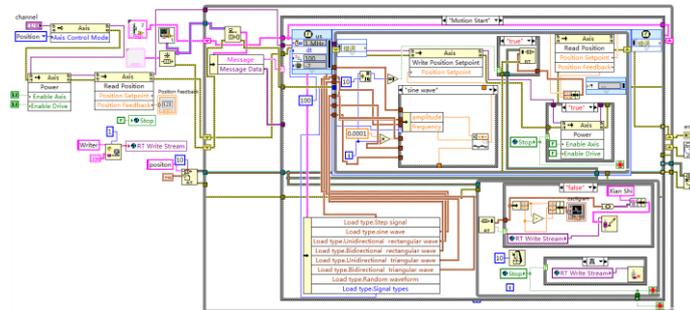


Fig.7 The motor control program

4.3.2 Data Acquisition Module

DAQmax, a data collection channel independently developed by Ni company, is used to build the data collection part, and the data is transmitted to the upper computer program for data processing and display in real time through the network flow [10]. The design idea of data acquisition module is shown in Fig.8.

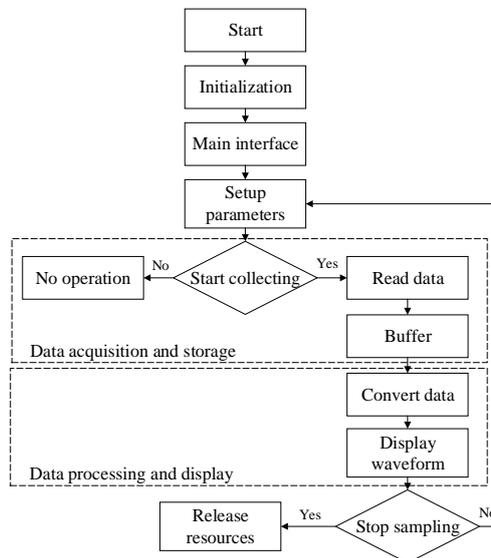


Fig.8 The design idea of data acquisition module

The data acquisition program is shown in Fig.9.

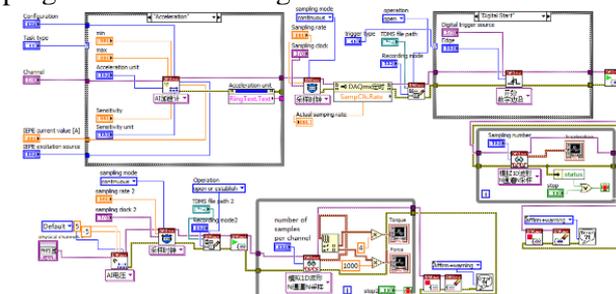
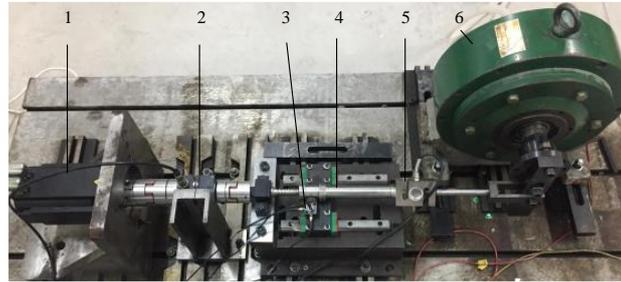


Fig.9 The data acquisition program

5. Experimental results

In order to verify the effectiveness of the ball screw pair high-frequency loading test bench, the inertial force loading test and rated speed loading test are carried out for a certain type of ball screw pair. The final test bench is shown in Fig. 10.



1-PMSM; 2-Torque speed sensor; 3-Accelerometer; 4-Ball screw pair; 5-Pull pressure sensor; 6-Magnetic powder brake

Fig.10 Photo of test bench

5.1 Inertial force loading test

The inertial force loading test sets the motor's motion form to a sine wave with frequencies of 6 Hz, 8 Hz, and 10 Hz. And the peak speed of lead screw at each frequency is required to be 1200 r/min , 1500 r/min and 1800 r/min respectively.

The formula for calculating the theoretical inertia force is as follows:

$$F_r = \frac{J_m \cdot \alpha}{r}$$

In the formula, J_m is the moment of inertia; r is the length of the arm; α is the angular acceleration of the magnetic powder brake. Therefore, the inertial force of the ball screw pair can be obtained only by the angular acceleration of the magnetic powder brake.

The output speed of the motor n is as follows:

$$n = n_{\max} \sin(2\pi ft)$$

The linear speed of the nut v_n is as follows:

$$v_n = n \cdot P_h$$

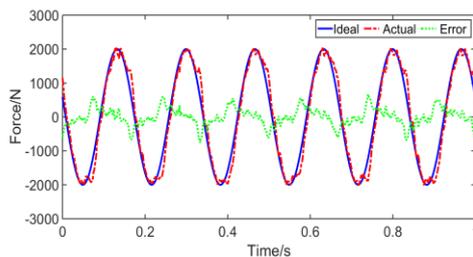
Derivation of v_n can obtain the angular acceleration of the magnetic powder brake α , which is as follows:

$$\alpha = \frac{2\pi f J_m n_{\max} P_h \cos(2\pi ft)}{r}$$

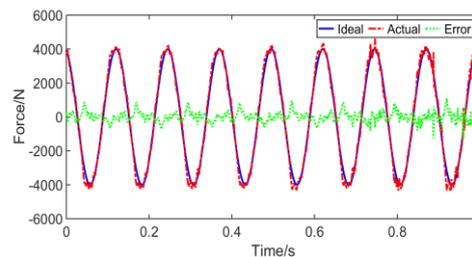
The axial inertia force of the ball screw pair F_r is as follows:

$$F_r = \frac{2\pi f J_m n_{\max} P_h \cos(2\pi ft)}{r^2}$$

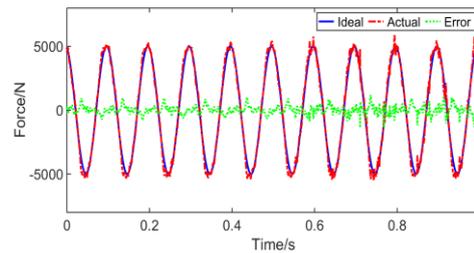
In the formula, $n_{s,\max}$ is the peak speed of lead screw, and its unit is r/s ; f is frequency; t is time, and its unit is s ; P_h is the lead of ball screw pair, and its unit is mm . The theoretical and actual inertial force curves at each frequency is shown in the Fig.11.



(a) Tracking curve at 6Hz



(b) Tracking curve at 8Hz



(c) Tracking curve at 10Hz

Fig.11 Inertial force tracking curve

It can be seen from the above figures that the actual inertial force curve measured by the force sensor is consistent with the change of the theoretical calculated inertial force curve, with good follow-up performance and few data mutations, under various frequency conditions. The test verifies the effectiveness of the inertia force loading of the magnetic powder brake.

5.2 Constant force loading test

The constant force loading test requires that the magnetic powder brake shall be controlled for axial loading when the speed of the lead screw reaches 1200 r/min , and the axial forces shall be 500N, 800N, 1200N, 1400N, 1700N and 2000N. The actual axial force is shown in Fig.12.

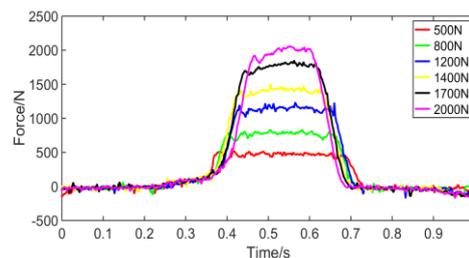


Fig.12 The actual axial force

It can be seen from Fig.12 that the axial force curve has a peak fluctuation phenomenon. The main reason is the slight hysteresis caused by the gap of the push rod in the rocker arm groove under high frequency conditions. In general, the axial force does not change much and is relatively stable, within the error range. Therefore, the test can verify the effectiveness of the axial constant force loading of the ball screw pair by using the magnetic powder brake.

6. Conclusion

In order to test a certain type of ball screw pair, a design scheme of loading test bench based on LabVIEW+PXI is proposed. The loading test bench can simulate various frequency working conditions and carry out the stable inertial force loading and the constant axial force loading test. In structure, the test bench is reasonable in design, reliable in performance, simple in operation and low in cost. In the control program, the frequency and amplitude control of the drive motor and real-time collection, processing of signals of various sensors are realized through the LabVIEW software and the PXI platform. The test bench has achieved the control requirements of the system.

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