An improvement design of multi-sensor test bench

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Abstract. Parallelism error is researched for a three-coordinate testing bench that simulates the automotive environment to test the performance of multi-sensor. The studies showed that the parallelism error between the sensor and the magnet and the signal wheel has an effect on the experimental data. A calibration device with multiple sets of force sensor probes was designed to improve measurement accuracy. And probe measurement results were used to compensate parallelism error in several directions. Results show that this method can reduce above-mentioned error and improve the accuracy of experimental data effectively.

1. System Design and Analysis

The requirements for vehicle stability and intelligence are increasing with the update and development of artificial intelligence and autonomous driving technology. As one of the information sources of automobile electronic control system, the performance of automobile sensor determines the performance of automobile to a large extent [1]. Therefore, it is very important to detect the sensor [2]. The speed sensor generates a pulse signal through the excitation of the signal wheel installed on the high-speed motor. In this study, the eigenvalues of the speed sensor waveform are tested under the variables of multiple target positions and multiple target speeds of the signal wheel. The position sensor moves along the lateral direction through the step size [3]. It outputs a signal when the magnetic field changes to generate an induced electromotive force. An electronic module base plate integrating sensors, gearbox control units and electrical interfaces is designed. Multiple above-mentioned two sensors are installed on it, which can be used to test its performance parameters.

1.1. Test bench design

The main requirements for the test bench:

- Position control accuracy: ≤0.01mm.
- Signal wheel mechanical phase calibration accuracy: ≤0.1°.
- System sampling accuracy: ≤0.01°.

In this study, the industrial control computer is used as the main control device, and the PLC is used to realize the motion control of the signal wheel spindle and the three coordinate axis where the multi-sensor is located. The NI board is used to collect the signals output by the multi-sensor.
The accuracy of the experimental data determines the quality of the test bench. In order to reduce the possibility of deformation of the equipment base due to stress and vibration during operation of the equipment, this study installed the key components of the equipment on the marble base.

Since the air gap between the sensor and the signal wheel affects the waveform of the sensor output, this study uses a linear motor to adjust the Y direction position in order to make the motion data of the motor in the direction of the sensor and the signal wheel more accurate. At the same time, a grating ruler is used to feed back the actual position to the servo drive, which improves the motion accuracy.

According to the original test results, the parallelism error showed in FIG.3, flatness error between the sensor fixture and the adapter of the signal wheel fixture installed on the device, and the error superposition caused by the shape and position tolerance of the fixture and the signal wheel itself will interfere with the test data. Therefore, older test benches cannot obtain more accurate data without eliminating this effect. Mechanical structure showed in FIG.1 and System structure showed FIG.2.

1.2. Improvement design

In order to reduce the impact of the above parallelism error on the experimental data, a calibration device showed in FIG.4 with multiple sets of force sensor probes was designed to adjust the parallelism between the sensor, magnet and signal wheel, combined with the adjustment device installed on the fixture, and ensure that the error of $\alpha$ is within 0.2° [4].

HEIDENHAIN TS260 is used as the force sensor, and the probe is triggered by an optical switch. The lens system converts the light beam emitted by the LED into parallel light and focuses it on the differential photocell. When the stylus deviates from the free position, the differential photocell sends
a trigger signal and transmits it to the main control system through the cable. The main control system also saves the actual position of the machine tool shaft encoder as a measured value and processes the measured signal. Then the above errors in X and Y directions are compensated by the adjustment device.

The parallelism between a signal wheel and a sensors fixture needs to be adjusted before using the combination for the first time. At the same time, after the adjustment is completed, the probe device can be easily disassembled.

In order to explore the effect of improvement design, several experiments are conducted before and after installing the above-mentioned device, and the characteristic values of the speed sensor waveform are tested within a certain number of revolutions of the signal wheel at a fixed speed, steering and relative position of the sensor signal wheel. The standard waveform characteristic values are shown in Table 1.

Table 1. Speed sensor output waveform characteristic values

| Parameter             | Min.  | Typ.  | Max.  | Unit |
|-----------------------|-------|-------|-------|------|
| Pre-low length        | 13.12 | 15    | 16.87 | μs   |
| Length of first pulse | 26.25 | 30    | 33.75 | μs   |
| Length of CCW pulse   | 78.75 | 90    | 101.25| μs   |
| Length of CW pulse    | 39.37 | 45    | 50.62 | μs   |

2. Development
The software system is mainly developed with LabVIEW, which completes the control of the position of the multi-sensor electronic module, the monitoring of the gap, the calibration of the signal wheel and the processing and analysis of the signal data [5,6,7].

The position adjustment of the multi-sensor electronic module is realized by the movement control of the three-coordinate table. The main control system controls the position of the servo motor and linear motor through the BECKHOFF PLC CX5120. Set the servo controller to the position control mode. The host computer controls the servo motor through a direction signal and a pulse signal. The number and frequency of pulses correspond to the position and speed of the worktable.

A variety of control methods are implemented for components, including fixed value control methods, jog control methods, and quantitative control methods. In this study, the real-time position information of the motor is transmitted to the servo drive through the coding port by using a grating ruler. BECKHOFF PLC is connected to the industrial control computer through Ethernet to communicate, and the absolute position information of the motor movement is transmitted to the main control system in real time, and displayed on the operation interface.

In this study, the NI PXI chassis was used for data acquisition, communication, and real-time control. The CAN FD board is used for communication with electronic modules. The analogue measuring board is used to collect and capture the rising and falling time of the speed sensor [8]. The digital measuring board is used to collect encoder data and indicate speed and angle changes. The FPGA board is used for frequency doubling encoder signals and processing real-time control requirements.

In this study, according to the required functions, the front panel of the multi-sensor test bench measurement and control system was designed. The parameter setting module, data acquisition module, data storage module, data playback module, signal analysis module and alarm module, pulse width adjustment module, and analogue collection module.
3. Experiment and Analysis

After the test bench was developed, the effect of the parallelism error between the sensor and the magnet and the signal wheel on the characteristic value of the speed sensor was explored. The test flow chart is shown in Figure 5.

![Experiment Flow Chart](image)

Among them, the air gap is controlled at 0.5mm, and the signal wheel speed is 2000r/min.

![Comparison Diagram of Characteristic Values of Speed Sensor](image)

It can be seen from FIG. 6 that in 10 sample measurements, compared with the original equipment data, the experimental data installed with multiple sets of force sensor probes has less fluctuation and smaller data tolerances. The test results prove that the scheme can effectively reduce the interference caused by the parallelism error and improve the accuracy of the experimental data.
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