DESIGN OF AUTOMATIC MEASUREMENT SYSTEM FOR PRE-TIGHTENING PARAMETERS OF MULTI-AXIS WRIST FORCE PRESSURE SENSOR

by

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Aiming at the shortcomings of low efficiency and poor accuracy of the existing pressure sensor pre-tightening parameter measurement system, an automatic multi-axis wrist force sensor pre-tightening parameter measurement system is designed. The multi-axis wrist force sensor module is used to collect real-time tension signal from the loaded hand wheel. After amplification, the signal is transmitted to the multi-channel gating module through RS485 communication module to realize the tested sensing. After fast switching and constant current source power supply control function, the data collector collects the pull signal obtained by multi-axis wrist force pressure sensor and transmits it to the upper computer of the system designed by LabVIEW through RS485 bus. The upper computer controls and collects the pressure sensor according to the pull signal feedback from the data collector, and the pre-tightening displacement of multi-axis wrist force sensor is determined by parameters such as axial displacement and friction resistance moment. The experimental results show that the designed system can fully measure the pre-tightening parameters of the sensor, and the starting moment measurement error is only 0.102%. The system can meet the requirements of batch measurement and calibration of multi-axis wrist force sensor with accuracy of 1%-0.1%.

Key words: *multi-axis, wrist force pressure sensor, pre-tightening parameters, automatic measurement, multi-channel gating, axial displacement*

Introduction

In recent years, sensors have been widely used in various fields, and pressure sensors are the most widely used. Multi-axis wrist force and pressure sensor is one of the most important parts of robot intelligent manipulator. Intelligent manipulator requires not only high position accuracy, but also the detection and control of force, moment and other parameters. This requires that the manipulator has force sensing function to facilitate the force control or compliance control of the manipulator [1]. Wrist force sensor is not only a kind of force sensor of manipulator, but also a strain sensor. It can directly detect the processing and force between robot and external environment. Multi-axis wrist force pressure sensor can simultaneously monitor the full information of 3-D space [2]. It is one of the most important sensors in manipulator force and position control. In the past, when measuring the pre-tightening parameters of multi-axis wrist force sensor, the measurement system based on virtual instrument was mostly adopted [3]. The computer and instrument hardware were integrated organically by software,

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the powerful computing and processing ability of computer and the measurement and control ability of instrument hardware were combined. This not only reduced the volume of the system, but also displayed the data in real time and analyzed the detection knot by software. The results are stored and recorded. However, this kind of pre-tightening parameter measurement system is mainly suitable for automobile and engineering machinery industry, and can only be used for a single measurement, with high cost, low efficiency and poor accuracy.

In order to solve these problems, this paper designs an automatic measurement system for pre-tightening parameters of multi-axis wrist force pressure sensor, which not only meets the actual needs of production tasks, but also has important practical significance for the popularization and application of multi-axis wrist force pressure sensor.

Materials and methods

Design of system integral structure

The whole structure of the system is shown in fig. 1. It consists of a host computer, a data acquisition device, a data acquisition controller, a programmable power supply and a multi-serial card. The system is equipped with pressure measuring and controlling instrument and thermostat to provide standard pressure and temperature environment for multi-axis wrist force pressure sensor. The acquisition controller is the core of the whole automatic measurement system [4]. Through the measurement and control circuit, the multi-channel selection of multi-axis wrist force pressure sensor and the logical switch of switch matrix are controlled to realize the pre-tightening parameters, voltage and electricity of the sensor bridge to be measured. The

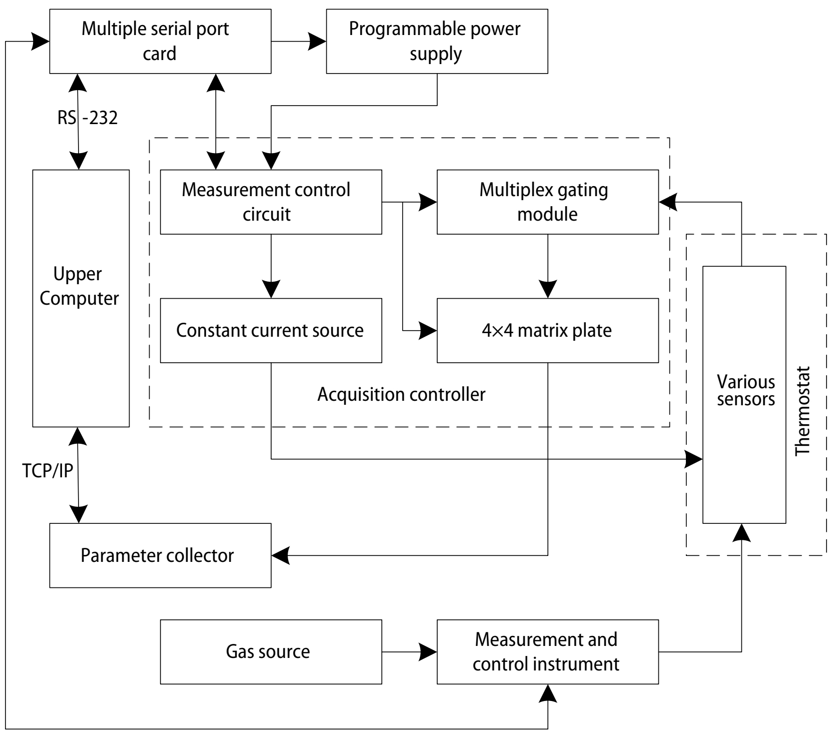

Figure 1. The whole structure of an automatic measurement system for pre-tightening parameters of multi-axis wrist force pressure sensor

cross-combination output of resistance and current points and multiple stable constant current sources are provided to ensure the stable measurement of the pre-tightening parameters of the whole sensor. The data collector completes the input signal acquisition function of the multi-axis wrist force sensor. The pre-tightening displacement of multi-axis wrist force sensor is determined by upper computer software according to the parameters of axial displacement and friction resistance moment.

Multichannel gate module

The multi-channel gating module mainly realizes the fast switching of the tested sensors and the power supply control function of constant current source [5, 6]. The low-on resistance and high-speed switching functions of 90 sensors and 450 channels are designed and implemented. Figure 2 shows the switching logic of the gated control module. The switch used to switch on five signal lines can be realized by selecting a 4-knife or 2-knife relay. The power supply control switch must be controlled by a separate relay [7]. Among them, Rx is the sampling resistance of current measurement [8]. A single channel card can provide 8 sensors and 40 channels for measurement switching. The card is connected with an external connector of 37 pins.

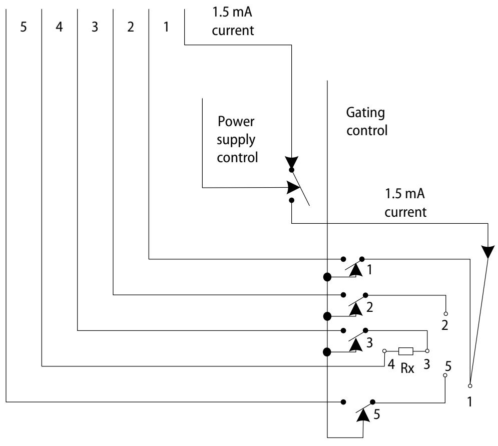

Figure 2. Structural design of strobe control module

On the basis of the aforementioned, the specific software part design is carried out.

Software design

System software function design

The computer software is realized by LahVIEW graphical software. LahVIEW provides the most commonly used and complete graphical development environment. For highly automated test systems, test management software provides a framework for sequential execution, branch/loop, report generation and database integration. The graphical programming method is direct and simple, which makes the program more convenient and reduces the development time of the program [9]. The pre-tightening parameters automatic measurement software mainly realizes the pre-tightening parameters automatic measurement function of 90 multi-axis wrist force sensors, stores and calculates the collected parameters [10, 11]. Firstly, the program initializes the acquisition, including the selection of communication port and communication rate, the measurement parameters of the collector, measurement channels, calibration points and travel numbers. According to different test needs, the switch of channels is controlled, the power supply of constant current source is controlled, the axial displacement of the multi-axis wrist force sensor is monitored, and the corresponding pre-tightening communication is carried out according to the set calibration points and travel numbers. Data acquisition is stored in the database [12]. After acquisition, the accuracy and linearity of the multi-axis wrist force sensor are calculated, and the results are displayed. At the same time, the data printing function is provided.

Determination of pre-tightening displacement

(1) Axial displacement of bearings for multi-axis wrist force pressure sensor

According to reference [13], it is known that the axial displacement of bearings of multi-axis wrist force sensor is as follows:

$$\delta_a = \frac{0.000077 F_a^{\ 0.9}}{(\sin\alpha)^{1.9} Z^{0.9} L_{we}^{\ 0.8}} \tag{1}$$

where δ_a is the axial displacement of bearings of multi-axis wrist force sensor, F_a – the axial load of bearings of multi-axis wrist force sensor, α – the contact angle of bearings of multi-axis wrist force sensor, Z – the number of bearings of multi-axis wrist force sensor, and L_{we} – the effective length of bearings of multi-axis wrist force sensor.

From eq. (1), it can be seen that the axial displacement is proportional to the 0.9 power of the axial load. Approximately, the linear relationship between the axial displacement and the axial load of the bearing of the multi-axis wrist force sensor can be considered [14]. Thus, the deformation curves of the axial load and the axial displacement can be drawn.

(2) Principle of friction resistance moment measurement

Friction resistance moment refers to the magnitude and dispersion of the friction moment of the multi-axis wrist force sensor shafting. Its magnitude determines the power consumption of the multi-axis wrist force sensor. This will lead to the temperature rise or even failure of the multi-axis wrist force sensor. It is an important index for evaluating the comprehensive performance of the multi-axis wrist force sensor [15]. The frictional resistance moment of multi-axis wrist force pressure sensor is influenced by structure design, processing conditions, lubrication conditions and service conditions.

In general analysis and calculation, the sliding friction moment caused by rolling contact and the friction moment caused by the viscosity of lubricating oil are very small, so it can be ignored. The formula for calculating friction resistance moment is:

$$M = M_E + M_S + M_C \tag{2}$$

where M_E represents the rolling friction moment of the multi-axis wrist force sensor, M_S – the relative sliding friction moment of the rolling object of the multi-axis wrist force sensor, and M_C – the differential sliding friction moment between the contact surfaces of the multi-axis wrist force sensor.

Equation (2) shows that the friction resistance moment is the sum of the moments that prevent the harmonic reducer from turning when it rotates. Friction resistance moment can be divided into dynamic resistance moment and static resistance moment. Static resistance moment refers to the friction resistance moment needed when the input shaft of harmonic reducer moves from static state to critical state, which is actually the starting moment in the previous section. Dynamic resistance moment refers to the friction resistance moment needed when the harmonic reducer runs steadily at a certain speed. Because the harmonic reducer is rotating when it works, the dynamic friction resistance moment is an important parameter to measure the dynamic performance of the harmonic reducer.

The measuring principle of friction resistance moment is based on balance principle. A standard value moment is applied to the input shaft of harmonic reducer to balance the friction resistance moment produced by the harmonic reducer when it rotates. At this time, the applied standard moment is equal to the friction moment value of harmonic reducer. In addition, friction resistance moment is a function of rotation angle.

$$M = f(\theta) \tag{3}$$

where f is an exponent.

(3) Measurement of bearing pre-tightening of multi-axis wrist force pressure sensor

Since the axial displacement is pre-tightening, whether the bearing has run-in or not has little effect on the bearing displacement, this method does not need to consider whether the bearing has run-in or not. The precondition of this measurement method is that the fit of bearing, shaft and seat hole of multi-axis wrist force sensor is interference fit, and if it is clearance fit, the axial deformation will increase.

At present, the manufacturer basically measures the starting friction moment of the bearing, draws the linear relationship between M_S and F_a based on the sliding resistance moment of the inner ring of the bearing and the end face of the roller of the multi-axis wrist force sensor, determines the appropriate preload according to the relationship diagram, and determines the axial preload displacement according to the preload eq. (1). If a manufacturer develops a new tapered roller bearing with multi-axis wrist force sensor, the parameters of which are: $\alpha = 20°$, $Z = 17$, $L_{we} = 37.4$ mm, then:

$$M_S = 0.489 F_a \tag{4}$$

According to eq. (4), the relationship between δ_a and F_a is obtained, that is, the axial pre-tightening displacement of multi-axis wrist force sensor is obtained.

Experimental analysis

Taking a certain type of multi-axis wrist force pressure sensor as the experimental object, the automatic measurement system of pre-tightening parameters of the multi-axis wrist force pressure sensor designed in this paper is tested from the aspects of pre-tightening assembly test, start-up moment test, friction resistance moment test and so on.

Pre-tightening assembly test experiment and result analysis

Introduction of experiment

The purpose of the experiment, tab. 1, is to test the relationship between the axial loading force and the height difference between the inner and outer rings of the bearing.

Table 1. Experiment related settings

Parameter	Operation and principle
Principle of experiment	Combining the method of pre-tightening the displacement change control of bearing inner and outer rings with the method of spring pre-tightening
Experimental device	Pre-tightening assembly test device
Measured parameters	Axial loading force, bearing inner and outer ring height difference
Experimental temperature	20 °C
Experimental humidity	55%

In the experiment, the axial tension of the spring is unloaded by loading handwheel, and the bearing of the experimental object is installed at the designated position according to the test requirements. Three sets of displacement sensors are slided to the top of the outer ring of the bearing through the sliding platform on the pre-tightened assembly test box, and the switch of the gas storage tank is opened to supply air for the cylinder displacement sensor. Then, the electric cabinet is powered on, and the system is used to start testing.

Analysis of experimental results

Under the previous experimental conditions, the preload of the experimental object is tested by the system in this paper. The relationship between the axial preload and the height difference between the inner and outer rings of the bearing is shown in fig. 3.

Analysis of fig. 3 shows that when the axial preload is less than 400 N, with the increase of preload, the height difference between the inner and outer rings of the bearing increases, and the relationship between them is almost linear. When the axial preload force is greater than 400 N, the height difference between the inner and outer rings of the bearing varies little, because the mechanical limit mechanism of the bearing starts to work.

Friction resistance moment testing experiments and result analysis

Introduction of experiment

The purpose of the experiment is to test the relationship between the friction resistance moment and the rotational speed of the input axis.

- Experimental Principle: Using dynamic balance testing method to measure starting torque of experimental object.
- Experimental device: friction resistance moment measuring device.
- Measured parameters: input shaft rotation speed, friction resistance moment.
- Experimental temperature: 20°C.
- Experimental humidity: 55%.

In the experiment, the experimental object is first installed on the precise steel body test bracket to ensure that the coaxiality between the experimental object, the torque sensor and the servo motor is within a certain range.

Analysis of experimental results

The frictional resistance moment of the experimental object is measured by the system in this paper. The relationship between the frictional resistance moment at different rotational speeds and corresponding rotational speeds is shown in fig. 4.

Analysis of fig. 4 shows that with the increase of rotational speed, the friction resistance moment increases in an approximate linear relationship, which shows that rotational

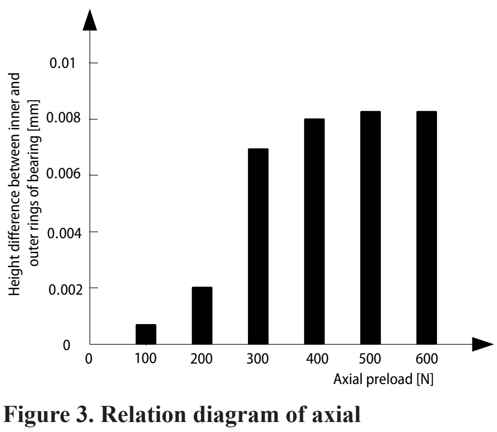

Figure 3. Relation diagram of axial pre-tightening force and height difference of bearing inner and outer rings

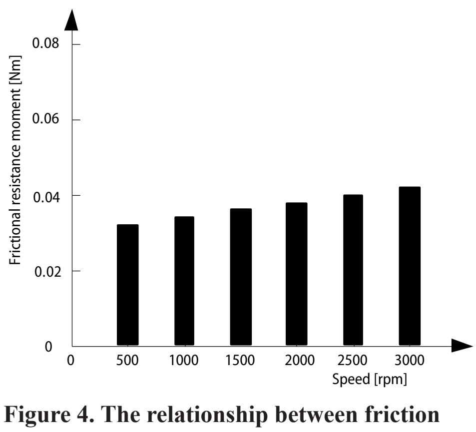

Figure 4. The relationship between friction moment at different rotational speeds and corresponding rotational speeds

speed is one of the main factors affecting the friction resistance moment of the experimental object. However, with the further increase of rotational speed over 500 rpm, the trend of increasing friction resistance moment is not obvious, because the preloading force of bearing is the key factor affecting friction resistance moment during preloading assembly of experimental object.

Discussions

In the third part of this paper, the related experiments are carried out on the pre-tightening parameter automatic measurement system of multi-axis wrist force pressure sensor. The experimental results show that the height difference of each displacement sensor is gradually increased with the increase of axial pre-tightening force. When the pre-tightening force is less than 400 N, the height difference between the inner and outer rings of the bearing object increases with the increase of the pre-tightening force. When the axial pre-tightening force is greater than 400 N, the height difference between the inner and outer rings of the bearing of the experimental object changes little. As the axial preload force increases, the difference between the forward starting torque, the reverse starting torque and the starting torque test value is less than 0.03 Nm, when the axial preloading force is less than 400 N, the shafting starting torque varies with the preloading force; when the axial preload is greater than 400 N, the starting torque is no longer increased. The frictional resistance torque increases with the increase of the rotational speed, but after the rotational speed exceeds 500 rpm, the tendency of the frictional resistance torque increases gradually. The system can meet the requirements of batch measurement and calibration of multi-axis wrist force pressure sensors with accuracy of 1%-0.1%. Add data management capabilities.

The software part of the system can save the measurement data, but only save the huge measurement data in a certain path of the control host. It does not have the ability to analyze, filter and measure the parameters. Therefore, it is necessary to establish a database to increase data management capabilities.

Conclusions

In this paper, a multi-axis wrist force sensor pre-tightening parameter automatic measurement system is designed for sensor pre-tightening parameters.

- Through hardware devices such as multi-channel gating module and multi-axis wrist force sensor module, the pre-tightening parameters of multi-axis wrist force sensor or transmitter in the measurement process are automatically and accurately measured and recorded, and the multi-axis wrist force sensor is automatically realized.
- The experimental results show that the system can not only measure the pre-tightening parameters of multi-axis wrist force sensor comprehensively, but also meet the requirements of batch measurement and calibration of multi-axis wrist force sensor with accuracy of 1%-0.1%.
- In the future, the anti-interference of the pressure sensor will be studied to effectively improve the current stability of the pressure sensor.

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