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RESEARCH ARTICLE

DESIGN OF INTELLIGENT DETECTION DEVICE FOR BEARING STEEL BALL

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ABSTRACT

Based on the meridian expansion method, a mathematical model for the analysis of the unfolding motion of the bearing steel ball surface is established, and the trajectory equation of the unfolding motion of the ball surface is deduced, which provides a basis for the follow-up mechanical structure design. Through the mechanism simulation based on Pro/Mechanism, the scanning trajectory curve of the probe can be verified and the surface of the steel ball can be completely covered. According to the comprehensive consideration of the cost and performance of the system, the hardware composition and selection of the system are established. Through C language program, the single chip computer, data acquisition card, stepper motor and so on are automatically controlled, and the high efficiency work of mechanical structure is completed.

INTRODUCTION

Surface quality of steel balls has a key impact on the service life and working stability of bearings. Especially some steel balls used under high pressure and high speed conditions, their surface quality problems, such as scratches, cracks, pits, etc., are very prone to extend and expand, leading to bearing failure and even cause accidents. In order to ensure the reliability of bearing work, in the bearing production industry, the acceptance of steel ball surface quality must pass the relevant testing or testing. For the general steel ball production enterprises, the inspection of steel ball surface quality mainly relies on manual methods, and the detection efficiency is limited. The problems caused by the low accuracy and automation of manual inspection, high labor cost and management cost have become a persistent problem in the market competition of steel ball production. At present, there is no domestic testing equipment for steel ball surface defect detection in the domestic market, and the steel ball manufacturers urgently need this automatic testing equipment to meet the needs of enterprise development. In order to improve the quality of steel ball production and realize the automatic detection of sub-surface defects on the surface of steel ball, a device which can realize the automatic detection of sub-surface defects on the surface of miniature steel ball is proposed and designed. Through the design and verification of its automatic control system, the intelligent, efficient and accurate detection effect is realized.

Surface Expansion of Steel Ball Model

Surface deployment mechanism of steel balls: The commonly used spherical expansion methods include conical, cylindrical and meridian expansion methods. Cone method, as shown in Fig.1a, divides the whole sphere into spherical belts similar to cones and unfolds them according to cones. Cylindrical method, as shown in Fig.1b, divides the sphere into willow-leaf spheres along the meridian. Each sphere is approximately replaced by a tangential cylindrical surface, and then expanded according to the cylindrical surface. Meridian expansion method, as shown in Fig.1c, detects the probe rotating around the ball and sets the rotating track as a helix. Whether the helix can completely cover the surface of the ball depends on the area covered by the detector and the density of the helix. According to the different deployment mechanism of steel balls, the surface detection mechanism of steel balls with different working principles can be derived. Based on the meridian expansion method, the unfolding motion characteristics of steel balls are studied in this paper. The detection mechanism of meridian deployment is compact and easy to operate, and can simultaneously complete eddy current defect detection, vibration detection, infrared laser surface detection and so on. The completeness of steel ball deployment is the key to surface quality inspection. If the steel ball surface deployment is incomplete, the information of local spherical surface of steel ball cannot be effectively processed.

Mathematical model of surface deployment: For the meridian expansion method, its expansion trajectory is a complex three-dimensional helix. When determining the trajectory equation, it is necessary to use a reasonable coordinate system according to the expansion motion parameters, that is, coordinate transformation of the original coordinate system in three-dimensional space. Assuming that the original coordinate system of the steel ball is $O\text{-}xyz$, keeping the origin and z coordinate axes unchanged, rotating the X and Y coordinate axes around the origin counterclockwise, the coordinate system $O\text{-}x'y'z'$ is obtained, as shown in Fig.2.

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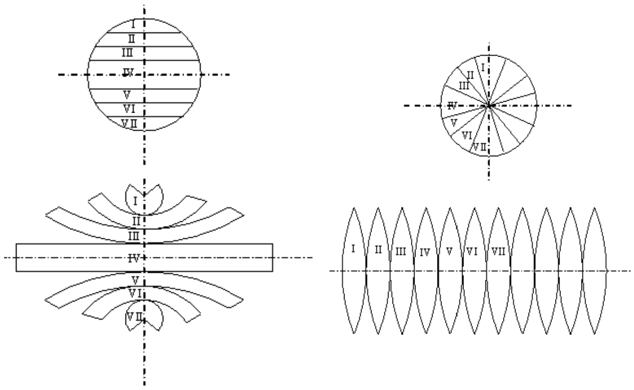
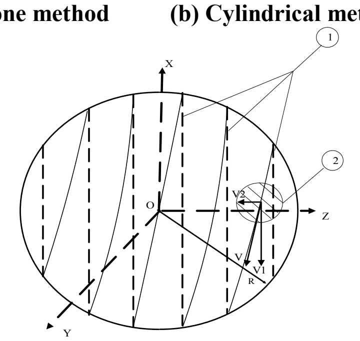


(a) Cone method (b) Cylindrical method



(c) Meridian expansion method

Fig. 1. Steel ball expansion diagram

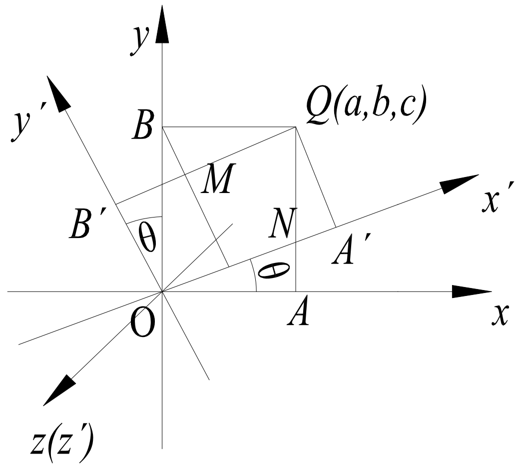


Fig. 2. Rotating diagram of the expanded coordinate system

$$\begin{cases}|OA'| = |ON| + |NA'| = |OB|\sin\theta + |OA|\cos\theta \\ |OB'| = |NB| - |MB| = |OB|\cos\theta - |OA|\sin\theta\end{cases} \quad \text{..........(1)}$$

The matrix forms are as follows:

$$\begin{Bmatrix}|OA'| \\ |OB'|\end{Bmatrix} = \begin{pmatrix}-\sin\theta & \cos\theta \\ \cos\theta & \sin\theta\end{pmatrix}\begin{Bmatrix}|OA| \\ |OB|\end{Bmatrix} \quad \text{…………(2)}$$

Spreading Motion Simulation of Steel Ball Surface

Establishment of inspection mechanism model: In the design of the detection mechanism, besides the trajectory equation of meridian deployment mode, the installation of sensors should also be considered. In the process of automatic inspection of steel ball surface, it is necessary to control the rotating speed of steel ball and the scanning speed of eddy current sensor so as to realize the complete deployment of steel ball surface.

As shown in Fig.3, the tested steel ball rotates around Z axis between the two wheels by driving wheel and expanding wheel, and the contact between the steel ball and the two wheels is regarded as point contact. Ideally, the movement of the steel ball in the testing process is pure rolling, while the two eddy current sensors sigh 180 degrees and scan the steel ball in the direction of latitude and latitude. In order to ensure the existence of constraints between relative motion elements, in the process of model assembly, the motion connection between models is established to ensure the degree of freedom.

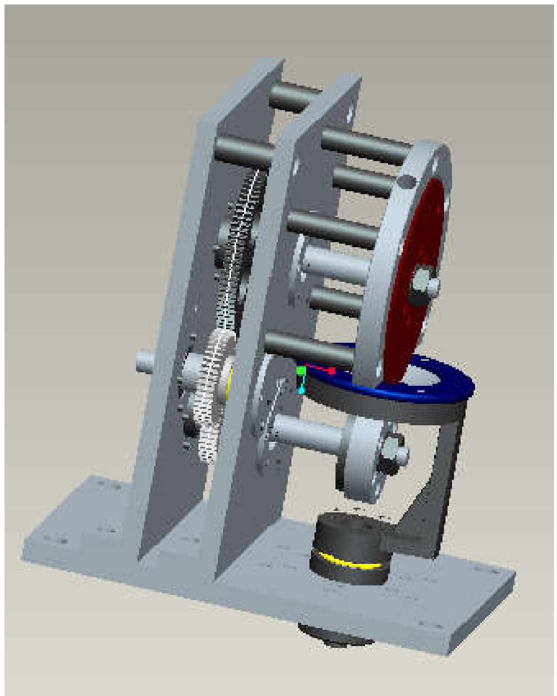


Fig. 3 3-D diagram of detection device

Kinematics simulation: Pro/Mechanism is used to simulate the movement of steel ball deployment detection. Set the speed mode of the probe scanning motor as Cosine. The direction of gravity, mass attributes, dampers and so on are defined respectively in the running environment. Finally, through a simulation, the scanning speed characteristics of the probe are obtained as shown in Fig.4.

The simulation results show that the angular velocity of the steel ball is 27.5 rad/s and the scanning angular velocity of the probe is 1.1 rad/s. The calculation shows that when the diameter of the tested steel ball is 8 mm and the diameter of the sensor probe is 2 mm, the scanning trajectory curve of the probe can completely cover the surface of the steel ball. Therefore, the steel ball will not be missed in the detection.

Control System Design

Hardware system

In this paper, according to the mechanical structure characteristics of the detection device and the deployment mode of the steel ball, the hardware of the automatic control system is established, which mainly includes single chip computer, step motor, synchronous motor, AC motor, data acquisition module and other components.

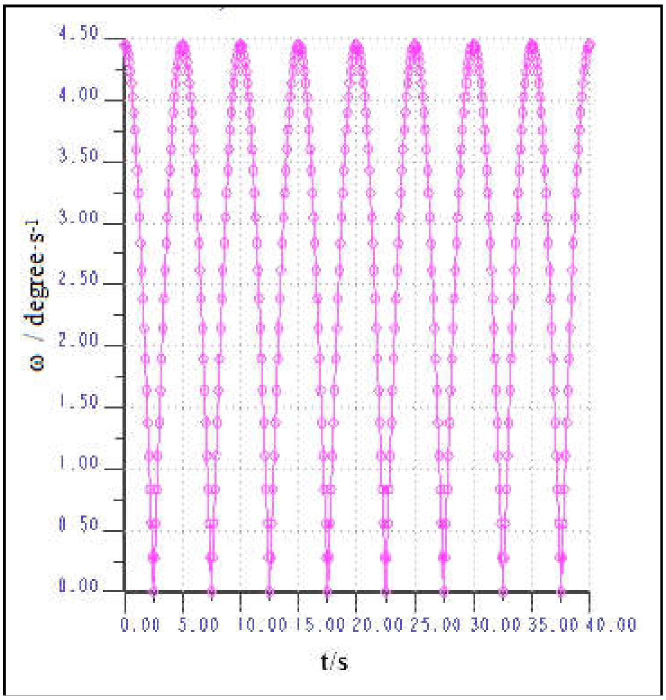


Fig. 4. Kinematics simulation

In recent years, SCM is more and more widely used in industrial automation control relying on its advantages of high speed, high performance, low voltage and low power consumption. Among them, MCS-51 has become the mainstream product of embedded control system. The SCM selected in this paper is based on 8051 core, which has fast processing speed and strong anti-interference ability. Some pins and minimal application systems of STC89S52RC are shown in Fig.5. P1.0-P1.7 is an 8-bit standard bidirectional I/O port with three LSTTL gates. RST is the reset end, high level effective, the width is more than 24 clock cycle widths. XTAL is the pin of the clock circuit, which connects the two ends of the external crystal oscillator.

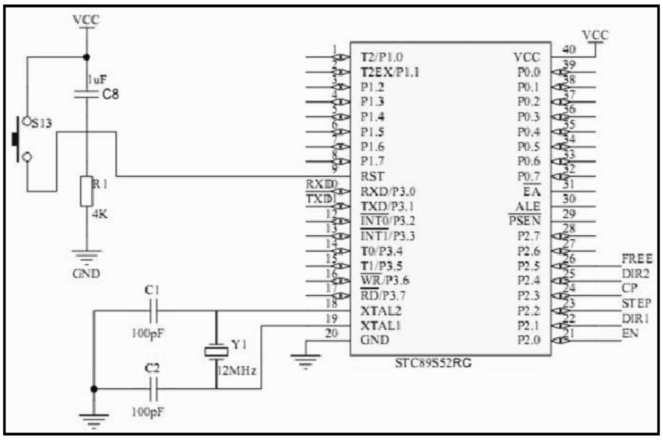


Fig. 5. Pin and minimum application system of single chip microcomputer

The data acquisition module used in the system is USB-4711A series, which can be plug-and-play. Installation does not need to open the installation board of the computer chassis. It can simply and efficiently collect data information. The data acquisition card can directly obtain all the required power supply through the power supply of USB port without external power supply. The scanning motor used in the system is a three-phase stepper motor. Its model is 57HS3A50-3506, the working voltage is 5.2V, and the stepping angle is 1.2 degrees. The hardware connection diagram of stepper motor is shown in Fig.6. The MCU sends the enabling signal through the pin P1.3, the pulse signal from P1.4, and the direction signal from P1.5.

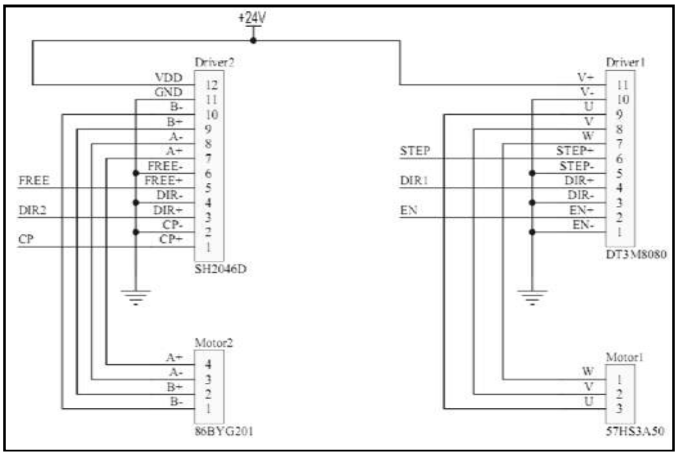


Fig. 6. Hardware connection diagram of stepping motor

Software system

According to the overall program block diagram of the control system, the control system is programmed with C language as the programming language, and with LabVIEW as the software platform, the data acquisition module is used for the front-end data acquisition system, and the acquisition results are tested and displayed. Under the action of load, the stepper motor works according to the set control scheme to meet two basic requirements: one is to determine the total number of steps needed to complete each movement. The other is to shorten the time needed to complete these steps as far as possible. The signal is collected by two 180 degree sensor probes on the equipment sensor bracket, and the data of steel ball surface defects are obtained. Before data acquisition, it is necessary to establish a channel, that is, set up sampling mode and sampling frequency, and determine the appropriate range of signals based on many experiments or experience, so as to get more accurate detection results. At the moment of completion of the detection, the signal collected on the surface of the steel ball is analyzed by the sensor detection circuit, and the test results are obtained. If the test results are within the standard range, the electromagnet closes and the steel ball enters the qualified ball box. If the test results are beyond the standard range, the single chip computer controls the solid-state relay to control the electromagnet to open and the steel ball enters the unqualified ball box. In this paper, batches of micro steel balls with diameter of 8 mm are tested, and the sampling frequency is set to 10 kHz. The data acquisition results are shown in Fig.7. Every time the system completes the scanning process, the sensor probe can collect about 5000 points on the surface of the steel ball, which can determine the completeness of the deployment of the steel ball. When the steel ball is qualified, the waveform in the waveform is gentle, even if there is a sudden change, the peak waveform will be relatively small; if the steel ball is not qualified, the waveform will change sharply. At the same time, the indicator lamp in the front panel can intuitively judge whether the surface of the steel ball is qualified. If it is not qualified, the green light will be on, and if it is not qualified, the red light will be on.

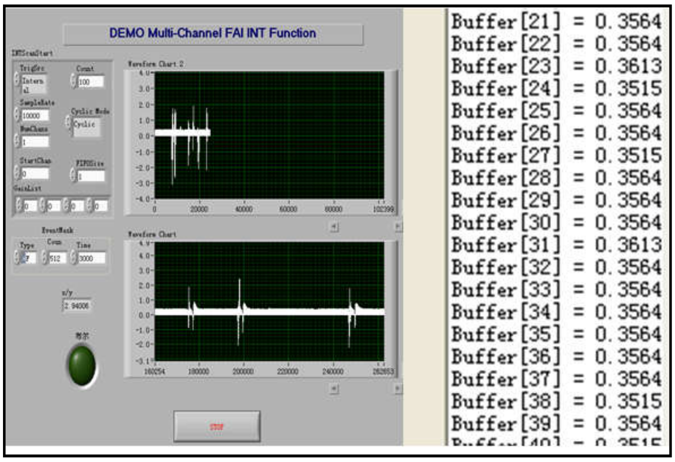


Fig. 7. Data acquisition results

Conclusions

The quality of bearing steel ball surface has an important influence on reliability work. Based on the meridian expansion principle, a non-destructive automatic detection device for surface subsurface defects of miniature steel balls is designed in this paper. Firstly, according to the deployment mechanism of the steel ball and the realization process of the deployment movement of the miniature steel ball, the trajectory equation of the surface deployment is obtained, the mechanical structure of the detection device is established, and the motion simulation is carried out based on Pro/Mechanism. Secondly, according to the driving principle of the device, the design scheme of hardware system is established. Based on LabVIEW software, the steel ball defect detection signal is collected and processed, and the automatic control can be completed by C language program.

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