Simulation and Experiments of an Intelligent Steel Ball Counter

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Abstract - In the production process of bearing, counting steel balls is a vital task. Traditional counting methods such as human counting or weighing not only result in large errors but also lead to efficiency too low to satisfy production requirements. With the rapid development of machinery and electronics industry, the production efficiency can be greatly enhanced by machines to replace traditional complex human work. Thus an automatic steel ball counter is urgently needed in industrial production. This paper presents an intelligent steel ball counter using two STC8051 series single-chip microcomputers as the CPU and a 12864 LCD as the display. The mechanical system and control system of the steel ball counter are also introduced in details. The device is able to accurately count steel balls 5-15mm in diameter and experiments showed that the mean accuracy of steel ball counting is 99.23%.

Keywords - Steel ball; intelligent steel ball counter; Single Chip Microcomputer; Simulation

I. INTRODUCTION

Counting of steel balls accurately is an essential task in bearing manufacturing process. Currently manual counting of steel balls is common in China [1-3]. Although some existing steel ball counters based on mechanical principles are employed in bearing production, these often provide unsatisfactory accuracy and require large amount of human work loads [4-8].

Therefore, an intelligent steel ball counter that is able to implement automatic counting has been urgently needed by industries [9-13]. However, so far there have not been many researches on steel ball counters. Wu H designed a steel ball filtering and counting device [14], which was based on mechanical method without a control system. Zhang D.D designed a counting device for an automatic steel ball packing system [15] and Zhan L designed a device for automatic counting and arranging steel balls [16]. However no details about the devices and experimental results can be found in literatures. Wang Z S, et al proposed a method of accurately counting steel balls based on image recognition technology [17], which could provide improved precision but the efficiency was still poor [18-20]. Therefore, the current steel ball counting devices still can not meet the requirements of industrial production [21].

In this paper, an intelligent steel ball counter based on photoelectric infrared detector is presented. The steel ball counter can be used to count steel balls whose diameters are from 5mm to 15 mm.

II. DESIGN OF THE MECHANICAL SYSTEM

A. General Design of the Mechanical System

The mechanical system of the steel ball counter consists of container cover, container, brace, step motor box, channel, infrared emitter, brush, chute, slot, display and display rack. The assembly drawing of the steel ball counter is shown in Fig.1.

The working process can be expressed as follows: when the plate of the container is opened, the steel balls roll down until they are stopped by the roller brush. Then the step motor drives the brush to rotate so that the steel balls are able to continue rolling down under the brush. Finally, the steel balls fell into the channel that has an infrared counter mounted on the top. Steel balls were divided into eight rows by the channel gate, and the infrared counter sensor at the top of the channel generates pulse signals when every ball passes through it.

Fig.1 Assembly drawing of the steel ball counter

1. Container-cover, 2.container, 3.brace, 4.step motor box, 5.channel, 6.the infrared emitter, 7.brush, 8.chute, 9.slot, 10.display and display rack.
is passed.

B. Design of other Key Structures

B1. Design of the container and bracket: The container was used to protect the steel balls and insulate sound or vibration. In order to overcome the thermal deformation and to help box cooling, the welded container was designed and a brace was added to allow the steel balls roll down, so that the number of steel balls can be counted. For large carrying capacity of the container, the brace needs to bear more weight and therefore the bracket as made of high strength martensitic steel, as in Fig.2.

![Fig.2 Schematic setup of the brace](image)

The expected total weight of steel balls is as high as 2 tons. Therefore, the pressure on each leg of the brace is 5000N. The cross-sectional area of the leg is 60mm², thus stress calculation can be expressed as:

\[
\sigma = \frac{F}{A} = \frac{5 \times 10^3}{60 \times 10^{-6}} = 83.3 \text{MP} 
\]

(1)

Stress intensity of the low-alloy high strength martensitic steel is 235MP, higher than the above so that can meet the requirements.

B2. Design of the Brush Supporting Shaft: Brush supporting shaft consists of three parts namely the step motor box, pillar support of brush and the chute of steel balls (see Fig.3). The rotating stepper motor drives the brush to improve the ball falling speed. Then, the steel balls roll into the chute rapidly and fall into the infrared counting device inside the channel.

![Fig.3 Schematic setup of the brush supporting shaft](image)

B3. Design of the Infrared Emitter Base: Schematic setup of the infrared emitter base is shown in Fig.4. The base of infrared emitter was made of metal tube. In order to set eight infrared sensors, 8 holes below the metal tube was prepared. This device was set on the channels. When a steel ball passes through the gate, the infrared sensor was activated to detect and count the ball at the same time.

![Fig.4 Schematic setup of the infrared emitter base](image)

B4. Design of the Channel: In order to count the steel balls conveniently, the channel gate was used to divide the steel balls into 8 rows. Because of the large impact force during the falling process, PVC material was chosen to produce the channel. The schematic setup of the channel is shown in Fig.5.

![Fig.5 Schematic setup of the channel](image)
Due to the uniform flow of steel balls in the channel, uniform load is applied on the surface of the channel. The diagram of bending moment is shown in Fig. 6. If choose the steel balls of the largest diameter as the test objects then the weight of each ball is 15g. According to the length of eight steel balls simultaneously cross the channel, the uniform load is 1200 N/m.

The maximum shearing force \( F_s \) on the top of the channel can be expressed as follows:

\[
F_s = ql/2 = 1200 \text{ N/m} \times 0.25 \times 0.25 = 300 \text{ N}
\]  \( (2) \)

The maximum bending moment at the central part of the channel can be expressed as:

\[
M = ql/2 = 1200 \text{ N/m} \times 0.25 \times 0.25 = 75 \text{ N/m}
\]  \( (3) \)

The stress of the shaft due to the maximum bending moment is:

\[
\sigma = \frac{M}{W} = \frac{75 \times 10^6}{2 \times 10^6} = 37.5 \text{ MPa}
\]  \( (4) \)

For PVB board with \( \sigma_b = 100 \) MPa, the maximum allowed stress when the board is subjected to symmetrical stress is \( \sigma = 55 \) MPa \( \geq 37.5 \) MPa, thus the board is safe.

B5. Design of the Channel Bracket

The channel and brush are bonded together. Because of the weak cohesive force, when the gravity center of the component was moved downward, the cohesive force cannot support the channel. Therefore, a channel bracket has been made using No.45 steel pipes. The bottom of the bracket was connected with the support column of the brace. The top of the bracket was connected with the bottom plane of the channel. An angled slat was welded at the bottom of the channels and the top of the bracket was made of thread black iron. The schematic setup of the channel bracket is shown in Fig. 7.

Due to large compressive stress on the channel bracket, the support needs pressure testing for stress checking. The stress on the support is mainly derived from the weight of the steel balls in the container and the channel. The compressive stress on the channel support was 700 N. Stress intensity can be calculated as follows:

\[
\sigma = \frac{F}{A} = \frac{700}{9 \times 10^{-6}} = 77.8 \text{ MPa}
\]  \( (5) \)

Stress intensity of steel was 200 MPa, which means this design of channel bracket can be satisfactory.

III. DESIGN OF THE CONTROL SYSTEM

A. General Design of the Control System

Block diagram of the system is shown in Fig. 8. A LCD panel 12864 was employed as the display device. There are 4 buttons on the control panel. Three of them were used to set the number of steel balls per bag. Two single chip microcomputers (STC89C52RC) were used as the CPU core. One of the single chip microcomputer was used to control the monitors and infrared sensors. The other was used to control the stepping motor and solenoid switch.
The principle of counting can be expressed as follows: at first, number of steel ball per bag, number of current steel balls, total number of steel balls and the number of bags were displayed on the LCD panel. Then, the number of steel balls per bag should be set. By pressing the start button, the stepping motor starts running. With the solenoid switch opened, the steel balls were falling down. Steel balls pass through the sensor and are detected by the sensor. Then the effects were converted to pulse signals and sent to the signal input interface of single chip microcomputer. Finally, the number of steel balls is shown on the LCD panel. When the counting number is close to the preset number, the solenoid switch was turned off.

B. Simulation of Circuit Diagram of the Control System

The circuit diagram of the control system is shown in Fig.9. The single chip microcomputer connects with the LED circuit. High level and low level can be produced by pressing the buttons. The display 12864 was controlled by the I/O ports P2 and P3. Eight buttons are connected with the 8 pins of P1 which were used to simulate high level and low level voltages. Switches were controlled by 3 buttons: P3.7, P3.5 and P3.6. Two pins P0.0 to P0.4 were used to control the rotational speed of the stepping motor.

C. Software Design of the Control System

At first, the number of steel balls per bag should be set. Then, the switch of the stepping motor was opened. Driven by the motor, the roller brush rotates and the steel balls were guided to the channel. When the steel balls pass through the sensor, the signal was sent to the single chip microcomputer. The processed signal was displayed on the
During this process, the solenoid switch was controlled by judging the number of steel balls for accurate counting. The flow diagram of the software was shown in Fig.10.

IV. EXPERIMENTS AND RESULTS

The photo of the steel ball counter was shown in Fig.11.

Three thousand steel balls with diameters of 5mm, 10mm and 15mm are selected for experiments. Then, these steel balls can be divided into 10 groups. The steel balls counter was employed in this test.

(a) Experimental results of the steel balls with diameter of 5mm.

(b) Experimental results of the steel balls with diameter of 10mm.

Fig.12 Results of the tests, continues on next page.
Fig.12 Results of the tests

Experimental results indicate that the accuracy of steel balls with diameter of 5mm, 10mm and 15mm were 98.9%, 99.7% and 99.1% respectively. The mean accuracy of steel ball was 99.23% (see Fig.12 (a)-(c)). Experimental results show that the accuracy of the steel ball counter still needs to be improved. One feasible way to increase the accuracy is to reduce friction caused by brush on the supporting shaft.

V. CONCLUSION

An intelligent steel ball counter has been designed using two STC8051 single-chip microcomputers as the core and 12864 LCD as the display. Accurately counting steel balls 5-15mm in diameter can be achieved. In addition, the counter has also been employed to count the number of steel balls whose diameters are 5mm, 10mm and 15mm respectively. Experimental results show that the accuracy of steel balls with diameters of 5mm, 10mm and 15mm were 98.9%, 99.7% and 99.1% respectively. The mean accuracy of steel balls was 99.23%. Therefore, the designed steel ball counting device is able to meet the requirements of industrial production.

REFERENCE