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Research on on-line monitoring technology for steel ball's forming process based on load signal analysis method

Ying-jun Li [a,b,*], Chang-sheng Ai [a], Xiu-hua Men [a], Cheng-liang Zhang [a], Qi Zhang [a]

[a] College of Mechanical Engineering, University of Jinan, Jinan 250022, PR China
[b] School of Mechanical Engineering, Nanjing University of Science and Technology, Nanjing 210094, PR China

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ABSTRACT

This paper presents a novel on-line monitoring technology to obtain forming quality in steel ball's forming process based on load signal analysis method, in order to reveal the bottom die's load characteristic in initial cold heading forging process of steel balls. A mechanical model of the cold header producing process is established and analyzed by using finite element method. The maximum cold heading force is calculated. The results prove that the monitoring on the cold heading process with upsetting force is reasonable and feasible. The forming defects are inflected on the three feature points of the bottom die signals, which are the initial point, infection point, and peak point. A novel PVDF piezoelectric force sensor which is simple on construction and convenient on installation is designed. The sensitivity of the PVDF force sensor is calculated. The characteristics of PVDF force sensor are analyzed by FEM. The PVDF piezoelectric force sensor is fabricated to acquire the actual load signals in the cold heading process, and calibrated by a special device. The measuring system of on-line monitoring is built. The characteristics of the actual signals recognized by learning and identification algorithm are in consistence with simulation results. Identification of actual signals shows that the timing difference values of all feature points for qualified products are not exceed ± 6 ms, and amplitude difference values are less than $\pm 3\%$. The calibration and application experiments show that PVDF force sensor has good static and dynamic performances, and is competent at dynamic measuring on upsetting force. It greatly improves automatic level and machining precision. Equipment capacity factor with damages identification method depends on grade of steel has been improved to 90%.

1. Introduction

Steel ball has been applied in many fields, such as electric power, building materials, mining, metallurgy, et al. [1–4]. It is the most important part in crushing industry and bearing industry [5,6]. The maximum working influence on bearings, which have strict requirement to vibration and noise, is coming from steel balls. Therefore, the quality of steel ball has business with quality of bearing. Many experiments show that the percent of influence factors on steel ball for bearing's noise is 60%. The ratio of bearing failure caused by destruction of steel ball is nearly 58.5%. It objectively describes the steel ball's position and importance in bearing industry. Cold heading process is the first step of steel ball machining.

* Corresponding author at: Nanjing University of Science and Technology, School of Mechanical Engineering, Dalian, Liaoning 116024, PR China. Tel.: +8653182765925; fax: +8653187154048.
E-mail address: dlutsmclyj@yahoo.com.cn (Y.-j. Li).

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The forming defects have diffusibility and heredity, and are often exposed in later process. They are the main source to produce quality hidden danger and defective productions. The forming defects are divided into three kinds, no ring, too large ring, and spherical eccentric.

There are many waste products carried out by abrasion of equipment, component's fatigue, and tool's breakage without any credible monitoring technology. Because monitoring process should be continuous in the steel ball production, hence on-line monitoring technology for steel ball's forming process should be researched to ensure product quality and satisfy the need of automatic production. By now, the researches on steel ball's forming quality are in experimental stage, and have not been used on actual steel ball production line. Therefore, present defect detection for steel ball manufacturing is still using artificial work [7–9]. However, there are some disadvantages of low detecting efficiency, high miss-detecting ratio, and bad quality stability. At the same time, the quality problems in production processes cannot be timely discovered by afterwards detecting ways. The lack of on-line quality monitoring component becomes to the bottleneck, which restricts the development of blank forming industry.

Along with the development of signal analysis technology, process control methods based on signal analysis are applied in many metal manufacturing industries. Waveform signals with abundant parameter information are used on on-line forging detecting systems to realize quality identification and fault identification. The cold heading force can be selected as characteristic signal to monitor cold header's production status. Force signal as reflection of cold heading force plays important role in process monitoring and fault diagnosis fields. The wave's vary of force signal can not only evaluate status of forging process, but also effectively forecast manufacturing quality.

Hitherto, scholars in the world had made many researches on theory and application by using force signal analysis method. Capan [10] made research on calculation method of the press force in a round shaped closed-die forging based on similarities to indirect extrusion. Backward extrusion method was used for the calculation of the required press load for the deformation of the material near the die-walls of a round shaped forging. Upset slab method of analysis was employed only for the section under the punch and the flash area. Jin [11,12] presented a methodology for developing a diagnostic system by using waveform signals with limited or with no prior fault information. The key issues studied in this paper were automatic fault detection, optimal feature extraction, optimal feature subset selection, and diagnostic performance assessment. A diagnostic system had been developed by using this methodology, and its performance continuously improved as the knowledge of process faults was automatically accumulated during production.

Kim [13] developed a methodology to detect profile changes of multichannel tonnage signals for forging process monitoring and to classify fault patterns. The changes included global or local profile deviations, which corresponded to deviations of a whole process cycle or process segment(s) within a cycle, respectively. The principal curve method was used to conduct feature extraction and discrimination of tonnage signals. The developed methodology was demonstrated with industry data from a crankshaft forging processes. Dong [14] made research on the stamping wave monitoring and its discrimination algorithm. Stamping forces were collected by using piezoresistive pressure sensor. ARM7 was used as the processing core to realize the signal analysis and feature extraction. Zhang [15] presented a study that used bispectrum to analyze the acceleration signals. The bispectrum could suppress Gaussian color noise to boost the signal-to-noise ratio. The experimental results showed that the method presented was effective and had a good potential for applications in shop floor.

The present researches have some certain guiding roles in on-line monitoring on cold heading's force characteristics [16–18]. However, specific theoretical analysis on steel ball's forming process is still need to be deeply researched. The relationships between change rule of die's force characteristic and steel ball's forming quality are also needed to be revealed.

Therefore, a novel on-line monitoring technology to obtain the forming quality in the steel ball's forming process based on load signal analysis method is presented, in order to reveal the die's load characteristic in cold heading forming process of steel balls. A mechanical model of the cold header producing process is established and analyzed by finite element method. The maximum cold heading force is calculated. A novel PVDF piezoelectric force sensor which is simple on construction and convenient on installation is designed. The sensitivity of the PVDF force sensor is calculated. The characteristics of PVDF force sensor are analyzed by FEM. The PVDF piezoelectric force sensor is fabricated to acquire the actual load signals in the cold heading process, and calibrated by a special device. The measuring system of on-line monitoring is built. The experimental results demonstrate that the method presented is effective and has a good potential for applications in shop floor.

2. Cold heading forming numerical simulation of steel ball

Cold heading forming principle of steel ball is analyzed. The mathematic model of cold heading mechanism is established. And then, cold heading process of steel ball manufacturing is simulated by the special finite element analysis software (DEFORM-3D) to obtained bottom die's dynamic load curves of ring defect and spherical eccentric defect with the change of time [19,20]. Single stroke steel cold heading machine (LD-130Z) produced by Jinan Shunda Steel Ball Machine Co., Ltd, China, is selected as the research object. The main technical indexes are shown as following. Diameter of die is 11.5 mm. Diameter of top material opening is 3 mm. Diameter of bar is 8 mm. Length of standard bar is 20 mm. Balling efficiency is 160 per minute. The flow chart of cold heading forming numerical simulation process by DEFORM software is shown in Fig. 1.