Study on Online Dimension Measurement Method of Large Ring Forging in Heat State

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Abstract. This work studied the model establishment for online measurement of the inner and outer diameters of large ring forging by analyzing the research status and combining the actual manufacturing condition of enterprises. One set of online measurement device was designed for non-contact online measurement of large ring forging. This device composed of green laser, CCD camera, guide rail, servo system, data processing system, etc. It can realize the distance size measurement of large ring with simple operation and high accuracy.

1. Introduction

Applied widely, the large ring is in a large demand. The main forming method is ring rolling which is a continuous and partial plastic forming process. Compared with integral die forging, this method has technical features of energy-saving, material-saving, high efficiency and high quality, so it becomes a main technology of large ring forming. This is also a forging process reducing wall thickness, expanding diameter and forming cross-sectional contour with graining as shown Fig. 1.

Figure 1. Ring Rolling part and Ring Rolling Machine

Large ring forgings include wheel and wheel hub, rings, and large gear blank which are mainly used in rail transportation, aerospace, military industry and other industrial fields. The utilization rate of large forging materials is low in China. Due to the inaccurate dimension measurement, the finishing allowance
is relatively large to ensure the subsequent processing [1]. In recent years, with the quality requirements of large rings getting higher and the market competition getting fierce in industrial fields, the accurate and effective graining of large ring forging becomes significant in future mechanical processing and final ring processing.

Given above reasons, large ring forging attracts many researchers from colleges, universities and scientific institutes to make great efforts to study the ring rolling process and field quality control. The forming mechanism is studied by finite element modelling to explore the effects of some main processing parameters on ring rolling quality to obtain the best ring rolling processing parameters. Online quality detection and control is studied to supplement the deficiencies of simulating analysis and actual difference in working condition. With the ring diameter getting increased, the diameter of current (super) large ring has reached 9m-10m, so the processing quality is more difficult to be controlled. Therefore, the rejection rate of rolling and the cost of material and processing further increase, while the processing efficiency greatly reduces. To solve this problem, it is urgent to realize real-time online detection of rings in graining. Therefore, the geometric dimension and dynamic performance of rings can be rapidly and accurately obtained to adjust the processing parameters and determine if forging should be determined to improve the product quality and processing efficiency, reduce rejection rate and effectively save energy.

2. State of the art

The geometric dimension measurement of large rings can be divided into contact measurement and non-contact measurement. Traditionally, the forging dimension can be mainly measured by non-contact method. Affected by the weight of measuring tool and surface temperature of forging, deformity may easily appear to cause low measurement accuracy. In addition, contact measurement does not adapt the requirement in modern industrial development due to the low measurement effectiveness and complex operation, so it has been gradually replaced with non-touch measurement. Current non-contact measurement methods mainly include acoustic measurement, electromagnetic measurement and optical measurement, while the optical measurement is the most widely focused and applied. According to different mechanisms, optical measurement can be divided into laser measurement, CCD visual measurement and structural optical measurement [2].

Laser measurement has two forms, laser beam projection and laser scanning [3,4]. Laser beam projection is mainly used to measure the length of ring, but not to measure the outer diameter or thickness. By laser scanning, three-dimensional shape of forging can be obtained to obtain geometric parameters of forging by data processing. Therefore, laser scanning becomes a research hotspot. An Italian company, Tecnogamma developed a system for detecting forging special dimension, Top-Scan which can measure the distance by laser triangle measurement to obtain the coordinates at the measured point. CAD three-dimensional modelling is used to process the measurement data to construct the outer contour of forging. A German company, Ferrotron Technologies GmbH developed a large forging measurement system, LaCam-Forge which can measure the dimension of forging appearance by reconstructing the three-dimensional model of forging by data matching and feature extracting. Zhang Yucun from Yanshan University realized the dynamic online measurement of outer diameter of forging by scanning outer section of rings with a two-dimensional scanner at each side of rolling mill. Du Zhengchun from Shanghai Jiaotong University established a model for the online measurement of heat-state forging dimension.

Nie Shaomin from Yanshan University studied a single-CCD imaging measurement system and applied this system to a forging factory. Liu Wei from Dalian University of Technology established an online measurement model for heat-state ring forging based on binocular vision to measure the outer diameter of heat-state trunk forging. Zhang Yucun, et al. from Yanshan University proposed a structured light vision measurement system based on linear structure light.

All of above methods can realize the measurement of forging dimensions to some extent, while some of them even realize the measurement of comprehensive forging dimension. Therefore, the foundation is set to improve the utilization rate and reduce the finishing allowance of forging material. However,
further analysis on above measurement shows that above measurement methods have deficiency when measuring geometric parameters of large ring in heat state. Theoretically, laser measurement can measure large forging in variety with high accuracy. But, current laser measurement neglects the effects of lost data which is caused by strong absorption of high-temperature forging. CCD measurement has simple measurement structure and accurate measurement result, so it can basically satisfy with the measurement requirement of large forging. However, affected by thermal noise and dust in forging field, the edge of forging cannot be correctly identified. Structure-light measurement technology has large range, high accuracy and easy extraction of optical strip information in projection, but it neglects the strong absorption of forging at high temperature. So, the optical strips in some projection structures cannot be displayed, affecting the measurement effects. In terms of completion, the current method can only measure the outer size of ring, but cannot measure the inner size.

This work proposed the outer measurement parameter model of large ring based on theoretical study on two-dimensional plane parameter solution. By this technology, the outer diameter can be detected for large ring by data fitting with data selected at measurement points on outer diameter. The indirect measurement of inner size based on surface temperature is used. The subject group designed a device to measure the inner and outer diameter of large ring.

3. Methodology
Mechanism of laser diameter measurement: Locate the center of a ring with three-jaw chuck. The measurement principle is shown in Fig. 2[5]. The laser released by Laser 1 returns to the laser once upon reaching the ring surface. Let transmission time be \( t \) and laser speed be \( C \), the distance to be measured, \( L \) can be calculated according to laser transmission time.

This work used pulse laser 1 to remit a light pulse to workpiece 2. The light pulse will be received by laser 1 after being reflected. The time difference \( t \) between these two pulses is measured with electric system and then the distance to be measured \( L \) is obtained. The distance between the center of rotary table and laser is constant, so the distance from the center to the point to be measured can be obtained.

Once upon the rotary table rotates to a certain angle \( \theta_1, \theta_2, \theta_3 \ldots \ldots \), a set of values corresponding to these angles, \( L_1, L_2, L_3 \ldots \ldots \) can be obtained. When installing the laser displacement sensor, the distance to rotatory center is constant, so the distance from the center to the point to be measured, \( R_1, R_2, R_3 \ldots \ldots \) can be calculated. If the coordinate of \( n \) measuring points on top circle is \( P_i(x_i, y_i) \), following formula can be obtained:

\[
x_i=R \cos \theta_i, y_i=R \sin \theta_i (i=1, 2, 3 \ldots \ldots n),
\]

Let the coordinate of center be \( (x_0, y_0) \), the ideal equation of this circle is [5]:

\[
(x_i - x_0)^2 + (y_i - y_0)^2 = R^2
\]
This circle is the least square circle. The square sum of distance from each point to be measure to the circumference of this circle is the least, that is,

\[ F(x_0, y_0, R) = \sum_{i=1}^{n} \Delta R_i^2 \]  

\[ \Delta R_i^2 = (x_i - x_0)^2 + (y_i - y_0)^2 - R \]  

By obtaining the extreme in principle of the least square method, the radium of the least square method \( R \) is the radium of ring to be measured [5].

\[ R = \sqrt{x_0^2 + y_0^2 - \frac{1}{n} \left[ 2x_0 \sum_{i=1}^{n} x_i + 2y_0 \sum_{i=1}^{n} y_i - \sum_{i=1}^{n} (x_i^2 + y_i^2) \right]} \]  

4. Result Analysis and Discussion

4.1. Online Dimension Measurement Method

According to the field investigation by Wuxi Paike New Material Co., Ltd., Zhangjiagang Hailu Duanjian Limited Company and other large-scale ring manufacturers, the subject group designed a device to measure the inner and outer diameter of large ring by comprehensively applying heat transfer theory and special and geometrical theory to establish a dimensional measuring model of inner and outer size and combining the boundary conditions, mechanics, mechanical structure design, sensor selection, etc. Fig. 3 and Fig. 4 show the schematic diagram and real object of this device, respectively.

**Figure 3.** Schematic diagram of online measurement device structure

1,4: Motor; 2. CCD; 3, 5. rotating platform; 6. Green laser

**Figure 4.** Real object of online measurement device

The system is equipped with guide rails and rotating platform in both vertical and horizontal directions. The guide rail and laser in horizontal direction are used to measure the outer diameter, while those in vertical direction used to measure the inner diameter. Given that the ring is in red and heat state, green laser is used to project to the surface of the ring to be measured and form a characteristic curve of bright color contrast. CCD camera can introduce the tangency between laser beam and ring edge by real-
time shooting of ring image. Laser can move along guide rail driven by servo system and feed the position information to computer through angle coding machine. When the laser beam is tangent with the relative positions of two edges, record the position information to obtain the outer diameter and length.

The measurement of outer diameter of large ring forging: Data fitting after measurement. According to the change rule of spatial geometry, a model for measuring the outer diameter of large ring is established based on linear green laser scanning and CCD camera. Green laser and camera should be installed in the horizontal rotatory device to make the measurement system adapt to the measurement of (ultra) large diameter. The solution to parameters in the model of measuring the outer diameter of large ring is studied based on the theory to two-dimensional plane parameter solution. The data of outer diameter to be measured is obtained to measure the outer diameter of ring by data fitting.

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4.2. Equipment accuracy
For the developed geometric parameter measurement system for large ring, the maximum diameter to be measured should be no less than 4000mm, the length no less than 0.5m, the measuring speed no less than 5m/60s, the accuracy of outer diameter no less than 5mm, the accuracy of length no less than 2mm, and the accuracy of inner diameter no less than 10mm. The equipment has high accuracy and stable operation, so it meets with the demands of the first production line of enterprises.

5. Conclusion
With the technology advancement in the application of large ring, the requirements on forming of large ring further improve, including the online dimensional measurement. This subject group developed corresponding measurement system to improve the accuracy by proposing an effective method of online measurement for geometric parameters of large ring in heat state. It can correctly measure if the large ring can reach the expected size to guide the parameter adjustment or graining determination, improve the processing accuracy and efficiency and reduce rejection rate.

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