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Review

An optical non-contact measurement method for hot-state size of cylindrical shell forging

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A R T I C L E I N F O

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A B S T R A C T

Using the present method the inner diameter cannot be measured. So an optical non-contact measurement method for measuring inner and outer diameters of cylindrical shell forgings is proposed. Firstly, an infrared dual-color temperature measurement system is devised based on the three-level interference filter. Secondly, the relationship between temperature and size is derived. Using this relationship the inner diameter is measured by combining the outer diameter and temperature. The outer diameter is measured by laser scanning technology and the temperature is measured by infrared temperature measurement technology. Thereby the measurement for hot-state size of cylindrical shell forging is achieved. Finally, the measuring method is feasible according to the experimental result.

Contents

1. Introduction

Large-scale forging is the key part of the large complete sets of equipments. With the development of the aviation, chemical industry and nuclear industry, the demand of large-scale forging is increasingly growing. Studying on the hot-state size measurement of large-scale forgings can elevate the precision manufacturing capability and international competitiveness. Meanwhile, the study has great significance to solve the bottleneck of manufacture precision in the large-scale forgings.

At present, the method of hanging wire is used to measure the diameter in the Japanese steel factory [1,2]; the method of two laser beams replacing the rope is used to measure the diameter in Korea [3]; the edge of forgings cross-section is measured with a movable camera in the Kobe Steel [4,5]; similar method is also used in the Korea Doosan Heavy Industries [6]; the length is measured by two lasers which load on the same rail projecting beam in Doosan Heavy Industries; the method of the pulse scanning is used to measure diameter in Italy, Switzerland, and

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the United States [7–9]; a great deal of researches have been carried out in Yanshan University. The research is focused on the size measurement of forging [10–13]. The length is measured by the lasers and the diameter is measured by CCD [14]. The high-accuracy on-line measuring for large forgings has been realized by the sensor of CCD in Shanghai Jiaotong University. But the measurement results are seriously affected by the ambient light and the coupling interference from the light of forgings. In addition, the CCD image recognition technique remains to be a further study at present [15–19]. Only the outer diameter of forging can be measured by the current methods. But the inner diameter size can not be obtained by direct measuring.

Combining laser scanning technology and infrared temperature measurement technology, a new measurement system for hot-state size of cylindrical shell forgings is designed in this paper. The infrared technology is based on the three-level interference filter. The measurement of the inner and outer diameters for the cylindrical shell forgings can be achieved by this system. This system has laid the theoretical foundation for the upgrading of the manufacturing capability and competitiveness of the cylindrical forgings in our country. Also, the working conditions of the forging workers can be improved. Additionally, the theory guarantee for the safe production of forgings should be provided by this system. The size of the outer diameter is measured by the laser scanning method. The size of inner diameter is calculated by establishing the relationship between temperature and size. At the same time the temperature and outer diameter is substituted into the relationship. The temperature is measured by infrared thermometry. While the accuracy of the current infrared sensors is relatively lower. The accuracy can not meet the requirements of inner diameter measurement. So the temperature of the forgings is measured by infrared dual-color temperature measurement technology based on three-level interference filter. The outer and inner diameters are measured by this way in this paper.

2. Measurement system of outer diameter

The measurement system is developed by using two laser scanners. The non-contact measurement is accomplished through this system. This system is composed of two angle measuring units and a distance measuring unit. The laser light angle is measured by angular encoder. The distance between the scanner and measured point is measured by distance-measuring sensor. The motor controller is controlled by computer to drive two motors. The angle rotation of the range finder is achieved by motor. At the same time, the distance from laser scanning sensor to the measured object is measured. Then the angle and distance measured by laser scanner is transmitted to computer. The 3D coordinates of a point on the measured object surface is obtained. With the rotation of scanning mechanism, a part of points' coordinates on the surface can be acquired. The surface of the measured forgings is reconstructed by point cloud data processing. So the outer diameter of forgings is obtained. The measurement system of the outer diameter is shown in Fig. 1.

Suppose the coordinate of a point M on the measured object surface of is (x_m, y_m, z_m). And the horizontal angle of the laser line is β, the vertical angle is γ. The distance from laser scanner to the measured point is S. According to Eq. (1), the 3D coordinates of the point M can be calculated.

$$\begin{cases} x_m = S\cos\beta\cos\gamma \\ y_m = S\cos\beta\sin\gamma \\ z_m = S\sin\beta \end{cases} \tag{1}$$

3. Measurement principle of inner diameter

The relationship between the radius and temperature is established through the thermal differential equation on the basis of the heat transfer in this paper. And combining the outer diameter size measured by laser scanner and temperature measured by infrared, the inner diameter size can be calculated.

Eq. (2) is heat conduction equation of measured object.

$$\frac{\partial t}{\partial \tau} = \frac{\lambda}{\rho c_p}\left(\frac{\partial^2 t}{\partial r^2} + \frac{1}{r}\frac{\partial t}{\partial r} + \frac{1}{r^2}\frac{\partial^2 t}{\partial \theta^2} + \frac{\partial^2 t}{\partial z^2}\right) + \frac{q^*}{\rho c_p} \tag{2}$$

where t is the temperature, τ is the time coordinate, ρ is the density, c_p is the specific heat capacity, q^* is the per unit

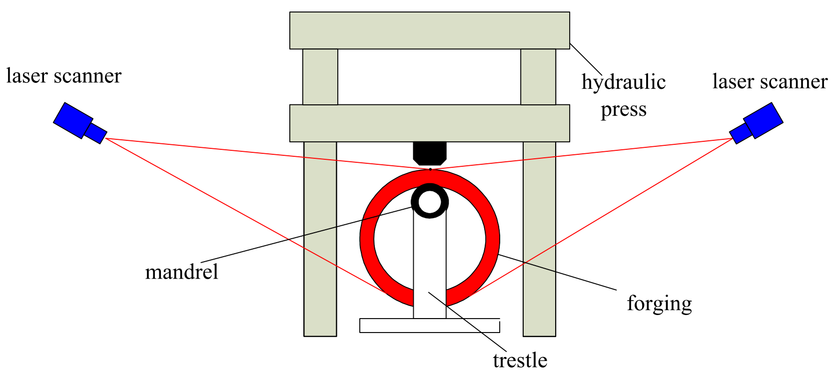

Fig. 1. Schematic diagram of outer diameter dimension measurement.