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Measurement and control technology of the size for large hot forgings

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ABSTRACT

Aiming at the different characteristics and measurement requirements of large hot forgings, a size measurement and control method is proposed. For irregular forgings, a measurement model based on line laser scanning is first constructed and then a solution of the optical center motion trail on the basis of the chessboard reference plane is proposed. The motion trail is solved according to the feature point coordinates on the reference plane in different frames. The overall three-dimensional size is finally achieved by combining the measurement model with the optical center motion trail. In addition, for regular forgings, under the guidance of images obtained by CCD, the two-dimensional size can be achieved according to the displacement of the line laser along the rail. Moreover, the size control of the forgings can be realized by rolling reduction control and the working position location. The measuring method proposed is feasible according to the experimental results.

1. Introduction

Large forgings are critical components in the large machinery equipments. Forging quality can impact directly on the overall level of major equipment and the operation reliability. During forging process, the real-time size measurement can usually provide significantly directive guidance meaning for making reasonable decision on the process parameters such as the next rolling pressure, rolling reduction and the number of rolling. Therefore, it is of great importance to obtain the size of large hot forgings accurately and timely. This study shows important actual meaning on improving the forging technology, the machining accuracy and the productivity in the forging process.

In the past decades, a large number of researches on the online size measurement of forgings have been done. Based on laser scanning and charge-coupled device (CCD) high-temperature imaging methods, the size measurement of small forgings was achieved by Hot-Eye coordinate measuring machines developed in OG Technologies of USA [1,2]; The binocular stereo vision measurement system was used in Kobe Steel of Japan to achieve two-dimensional size according to image processing [3,4]. Based on the principle of laser ranging, LaCam-forge system was developed in Germany [5]. Fu et al. [6,7] proposed an optical non-contact method to achieve the inner and outer diameters measurement of cylindrical forgings. The diameter of forgings was obtained by the use of images gray curve mutation points by Nie et al. [8,9]; On the basis of the laser scanning technology, the diameter measurement of the heated cylindrical forgings was achieved with the three-dimensional laser measurement system by Bokhabrine et al. [10]; The larger size measurement was achieved but only two-dimensional size could be obtained according to above methods. Jia et al. [11–13] put forward a method based on structured light projector and binocular vision to obtain better results, but feature matching needs further research. Gao et al. [14,15] designed a measurement system to achieve the 3D size measurement of forgings. This system is on the basis of two degrees of freedom spherical coordinate agencies and laser range finder, but it is inconvenient for the calibration of the spherical rotation accuracy and the center structure.

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In the present study, aiming at the different characteristics of the forgings and online measurement requirements, a size measurement and control method based on laser scanning is proposed. The method can both meet the size measurement requirement of the regular and irregular forgings. Moreover, the instruction of the rolling reduction and working position location can be indicated according to the high brightness and good direction performance of the laser line. And then the size control of the forgings can be achieved in the process of forging.

2. Measuring system

The size measurement system for large hot forgings, as shown in Fig. 1, is composed of the line laser, the CCD camera, the servo system and the guide rail. The system mainly accomplishes the following task units: (1) image acquisition; (2) motion control; (3) data processing.

The structure of measurement instrument is described as follows. A line laser projector and a CCD are installed on the sliding block at a certain angle. A green laser line is first projected vertically on the forgings surface and meanwhile the images of measured forgings are captured by CCD camera. According to different characteristics of the measured forgings, the line laser and CCD are controlled to do two-degree of freedom motion to scan the forging in different way along the vertical axis and horizontal axis. The captured images are transferred in time to computer to perform the data analysis and size measurement procedure. Accordingly, the size measurement of the forgings is achieved through processing these feature data. The proposed method can meet the size measurement requirement of both the regular and irregular forgings. Moreover, the instruction of the rolling reduction and working position location can be instructed according to the high brightness and good direction performance of the laser line. After that the images are sent to the computer and displayed in real-time. The model of the line laser projector adopted in this paper is MGL-III. The wavelength of the laser is 532 nm. The aperture angle is 30°. The model of the industrial CCD camera is MV-VE078SM/SC. The maximum resolution is 1024 × 768, and the size of a pixel on the CCD array is 4.65 μm × 4.65 μm. Servo motors and drives: MR-J2S-1 0A/B model. High-precision guide: BGXS45BE high precision linear guide rail, walking error is less than 40 μm.

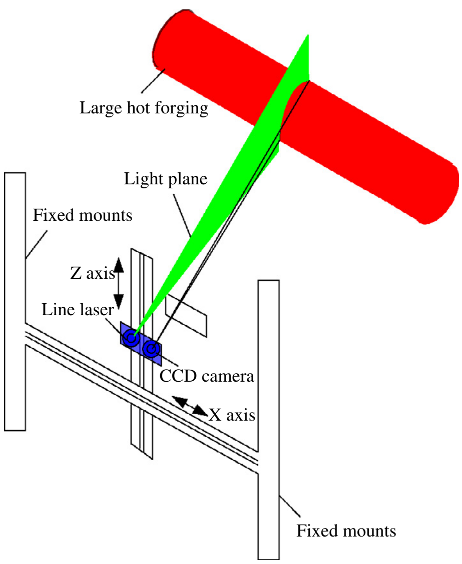

Fig. 1. Schematic diagram of the measurement system.

3. The principle of the measurement system

Based on the principle of optical triangulation, the size of the forgings can be achieved and further the geometrical size and the surface appearance parameters can be also obtained. In the above-described measurement system in Fig. 1, the sliding block is driven by the control of the servo system to scan the forgings along the guide rail. Then the data collected by CCD are transmitted to the computer and displayed in real-time. Meanwhile, a scanning measurement model is established, by which the three-dimensional information of each forging section is unified to one coordinate system. Finally, the overall size parameters of the forging can be constructed according to the partial information.

The measurement model based on laser scanning is shown in Fig. 2. It can be noted that the size information of the forgings is gained easily from the scanning data, which represents a direct contour map of the forging's surface. Any point $\boldsymbol{P}$ on the contour intersection line is taken. According to the corresponding relationship between the camera coordinate system and the world coordinate system, the three-dimensional coordinates of measured forgings in space are deduced by using the corresponding two-dimensional coordinates on the image plane. The relationship is given in Eq. (1):

$$s \cdot \boldsymbol{p} = \boldsymbol{K}[\boldsymbol{R}\,\boldsymbol{T}]\boldsymbol{P}_w \tag{1}$$

where s is the non-zero scale factor, $\boldsymbol{K}$ is the projection matrix. $[\boldsymbol{R}\,\boldsymbol{T}]$ is the transformation matrix. The transformation matrix indicates the relation from the camera coordinate system to the world coordinate system, in which $\boldsymbol{R}$ and $\boldsymbol{T}$ are the rotation matrix and the translation matrix between these coordinate systems respectively. They are

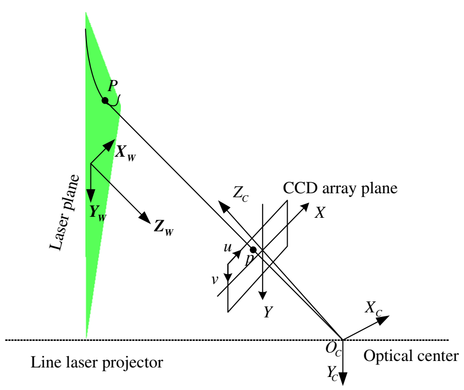

Fig. 2. The linear model of measuring coordinate system.