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An unsteady temperature field measurement method for large hot cylindrical shell forging based on infrared spectrum

Yu-cun Zhang, Bin Wei, Xian-bin Fu *

Yanshan University, Qinhuangdao 066004, China

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A B S T R A C T

At present, measuring the temperature field of large hot cylindrical shell forging in real - time remains a longstanding challenge in forging process. Aiming at the issue, an unsteady temperature field measurement method is proposed based on infrared spectrum in this paper. Firstly, combining the principle of primary spectrum pyrometry and three-stage Fabry–Perot cavity liquid crystal tunable filter (LCTF), an infrared temperature measurement system is devised to detect the surface temperature field of large hot cylindrical shell forging. Secondly, a two-dimensional unsteady heat transfer model of the forging is established. On the basis of the model and the obtained surface temperature field, the interior temperature field is acquired. Meanwhile, the new surface temperature field is continuously collected by the devised system. By repeating the above processes, the temperature field measurement of large hot cylindrical shell forging can be achieved. A clear advantage of the proposed method is that the whole temperature field real-time measurement can be achieved without knowing the value of the surface emissivity beforehand. Moreover, the influence of background light radiation on the measurement result is effectively inhibited. Finally, the feasibility of the method is proved by the experimental results. The method provides a new approach to temperature field measurement of hot cylindrical shell forging.

1. Introduction

Large cylindrical shell forgings are critical components in many significant national energy security fields such as nuclear power industry and petrified industry. The quality of large cylindrical shell forgings is directly related with the security of national energy and people's lives. Therefore, production ability of high quality products reflects national mechanical manufacturing level [1]. During forging process, the real-time and accurate measurement of temperature field, especially the interior temperature field, is an effective means to ensure the right carrying out of forging processes [2].

In the past decades, many scientists have explored the temperature field measurement method during forging processes. Using ANSYS software correctly, the numerical simulation was carried on the temperature field of TC21 titanium alloy during quenching process. On the basis of it, effect of cooling rate on microstructure was analyzed [3]. Dai et al. designed a multi-wavelength pyrometer based on multi spectral radiation thermometry. In addition to that, by using data process methods, the true temperature and spectral emissivity was accurately obtained [4]. With the help of non-linear finite element software MSC.Marc, Yuan et al. established two-dimensional finite element model of 35crmo steel large forging to simulate the transformation of the microstructure and temperature during quenching process [5]. Zhou et al. directly obtained three dimensional temperature field of combustion in the furnace by the use of CCD image measurement technology

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* Corresponding author. Present address: Yanshan University, Qinhuangdao City 066004, Hebei Province, China.

E-mail address: binxf2013@126.com (X.-b. Fu).

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[6]. An infrared dual-color temperature measurement system was designed by Zhang et al., based on the heat transfer between forging and oxide skin, the real temperature of forging was obtained [7]. Carlone et al. simulated the quenching process of the steel, and the internal relation between temperature field and solid–solid phase transformations was successfully revealed [8]. Although all these studies make great contribution to the development of temperature field measurement, a temperature field measurement method for large hot cylindrical shell forging that can be used in practical application has remained elusive. According to the present researches, temperature field measurement methods for large forgings mainly have two sorts [9]: one is to detect surface temperature field, and it is regarded as the whole temperature field of the forging. Without acquiring accurate information of the interior temperature field, this method is difficult to guide the implementation of forging processes. The other is to simulate forging processes and obtain the information of temperature field by the corresponding heat transfer model. Obviously, because of the idealization of measurement condition, the method is hard to meet the demands of engineering practice. So this paper focuses on proposing an on-line temperature field measurement method for large hot cylindrical shell forging that can be used in practical application.

In recent year, infrared temperature measurement has gradually become the most widely used measurement method with the advantage of convenient, smart, flexible, accurate and contactless [10,11]. In this paper, the surface temperature field of forging is detected by infrared temperature measurement system. Combining the obtained surface temperature field and two-dimensional unsteady heat transfer model, a new measurement method is proposed to acquire the whole temperature field of large hot cylindrical shell forging. The method provides a new approach to measure temperature field of large hot cylindrical shell forging in practical application. Moreover, unlike most traditional infrared temperature measurement, the method overcomes the effect of emissivity by applying an improved theory. What's more, the application of three-stage Fabry–Perot cavity LCTF helps the temperature field measurement system better adapt to the working environment. The research lays a solid theoretical and practical foundation for the on-line unsteady temperature field measurement of large hot cylindrical shell forging.

2. Measurement system

The temperature field measurement system is shown in Fig. 1. The system mainly has two tasks as follows. One is to measure the surface temperature field of forging. Based on this, the other is to calculate the interior temperature field by using two-dimensional unsteady heat transfer model.

The process of measuring surface temperature field can be described as follows. Infrared light from the measured forging enters into three-stage Fabry–Perot cavity LCTF through the rays condensation unit. After filtering, the uncooled microbolometer detector collects infrared light within a certain waveband and transforms the received light signal into electrical signal. Then, the electrical signal is transformed to corresponding digital data by the signal processing circuit and stored in computer for further datum processing. Meanwhile, the LCTF controller receives the command from computer to select the next suitable waveband (The electronic interfacing between LCTF controller and computer is nine-pin RS-232-C serial port, and the default baud rate is 9600). In the same way, as three-stage Fabry–Perot cavity LCTF successively selects three different wavebands, the computer records three groups of data along with it. Finally, the surface temperature field is obtained by the surface temperature measurement module based on the three groups of data.

When the new surface temperature field begins to be measured, the obtained surface temperature field is transferred to the heat transfer calculation module. By means of computer program calculation, the interior temperature field is acquired. Moreover, the calculation will keep going to simulate the variation of the whole temperature field until the new measured surface temperature field is received. The new measured surface temperature field is used as the initial condition for new round of calculation. Repeating the above processes, the unsteady temperature field measurement of hot cylindrical shell forging can be achieved.

2.1. Design of three-stage Fabry–Perot cavity LCTF

The principle of Fabry–Perot cavity LCTF is derived from Fabry–Perot interferometer. The principle diagram of Fabry–Perot interferometer is shown in Fig. 2.

According to the theory of engineering optics, the transmission wavelength λ should satisfy the following conditions [12]:

$$2nd\cos\theta = k\lambda \tag{1}$$

where d is the distance between two mirrors, n is the refractive index of medium, θ is incident angle, k is the order of interference ($k = 1, 2, 3, \ldots$). In FP-cavity LCTF, the structure of liquid crystal cavity is similar with F-P interferometer. According to Eq. (1), when k and θ are fixed values, transmission wavelength λ is determined by refractive index n and distance d. Therefore, when cavity length is fixed, Fabry–Perot cavity LCTF selects transmission wavelength by changing the refractive index of medium.

The change of refractive index depends on birefringent character of liquid crystal. Generally, FP cavity is filled with nematic liquid crystal. When electric power is cut off, liquid crystal molecules are parallel to the top and bottom substrates, and the refractive index of liquid crystal is n_e. When electric power is turned on, liquid crystal molecules gradually turn to electric field direction as the increase of voltage. Finally, the molecules can parallel to electric field direction. And the refractive index of liquid crystal is n_o. In this process, the refractive index of liquid crystal ranges from n_e to n_o, this is the so-called birefringent character of liquid crystal.

For Fabry–Perot cavity LCTF, the expressions of transmissivity T and Full Width at Half Maximum (*FWHM*) are given by Eqs. (2) and (3), respectively [13]: