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High-speed data acquisition of the cooling curves and evaluation of heat transfer coefficient in quenching process

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Abstract

The evaluation of surface heat transfer coefficients by using experiment measurement method is an inverse heat conduction problem. According to the characteristics of quenching process, a high-speed data acquisition system for measuring the temperature variations in a quenched part was set up by using industry standard architecture (ISA) in this paper. Cooling curves of P20 steel quenched in 20 °C and 60 °C water were acquired by using this system. A new method, which combines the finite element method (FEM) with optimization methods, was presented. The method can be used to evaluate the temperature-dependent surface heat transfer coefficient between the quenched part and quenchant in quenching process according to the temperature curve gained by experiment. In every time interval, the phase-transformation volume and the phase-transformation latent heat of every element are calculated by using FEM. The temperature and the phase-transformation volume of every element are calculated with the coupling calculation of phase-transformation latent heat.

Keywords: Data acquisition; Inverse heat conduction; Optimization; Heat transfer coefficient

1. Introduction

In industries, it is necessary to accurately determine the thermal physics parameters. The thermal physics parameters of materials usually vary with temperature. The conventional experiment methods are not satisfied with the requirement in some aspects. Therefore, much attention has been paid to the inverse heat conduction problem (IHCP) in recent years. The inverse heat conduction calculation has been widely used to accurately determine unknown physical quantities in practical engineering problems, such as the surface conditions, the initial conditions, the thermal properties of a body from known information measured at the prescribed positions. IHCP becomes one of the most important research subjects in thermodynamics area. It has the theoretical and engineering significance to study IHCP and to establish the numerical model of IHCP with good adaptability and high computation efficiency.

In forward heat conduction problems, the internal temperature field is derived from the known heating characteristics, boundary conditions and initial conditions of the body. The forward heat conduction problem is a well-defined problem, and

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it can be solved by using mathematical analysis method. But in the inverse heat conduction problems, the temperatures are measured at some interior points of the body, and then used to estimate the unknown boundary conditions on the external surface. Since IHCP is an ill-defined problem, it is more difficult to solve than the normal heat exchange problems [1,2].

In calculation methods of IHCP, the physical quantities that are easily and accurately measured are used to compute the physical quantities that are difficult to directly measure. In recent years, researchers in heat treatment area paid a high attention to the testing and evaluation of cooling performance of quenchant. When evaluating the cooling performance of quenchant, it is an ideal way to obtain the surface heat transfer coefficient between the quenched part and quenchant. But it is very difficult to measure the cooling rate or the surface heat transfer coefficient on the surface of quenched part. In this case, the transient calculation method of IHCP becomes a major method for solving the above problem.

Yao [3] set up a temperature data acquisition system to measure the temperature variations in the quenching process. The system can acquire, store and display the quenching temperature in real time, and has a simple data-processing capability. The temperature variations in the water quenching process were obtained by using this system and the flat probe. The temperature data was then used to determine the heat transfer coefficient between water and quenched part by finite difference method and nonlinear estimation methods. Gu [4] presented an inverse heat conduction model to compute the heat transfer coefficient according to the temperatures of quenching process measured by computer. The basic principles and the algorithm of calculating the surface heat transfer coefficient by IHCP method were introduced. But the influence of phase-transformation latent heat by using specific steel was not considered and the problem was supposed into one-dimensional heat conduction along the thickness of part in his study. Maass and Jeschar [5,6] described the measurements of the quenching behaviour exhibited by metallic specimens exposed to various quenching agents. The measured results showed that heat transfer was affected by some major parameters. In Maass's study, the temperature close to the surface was measured and used to estimate the heat transfer coefficient under different operating conditions. The results defined a relation between the heat transfer coefficient and the surface temperature. Other researchers [7–13] also studied the solution of temperature-dependent surface heat transfer coefficient, and presented several methods. But the latent heat due to the phase-transformation was not taken into account in all these research.

Although the latent heat of the phase-transformation is less than those of metal melting and solidification, it is an important factor affecting the temperature field and the phase-transformation because the latent heat of the phase-transformation can make temperature constant or rise in the positions away from quenchant. The latent heat and the phase-transformation fraction affect each other. When considering the latent heat, the oscillation of numerical values easily occurs in the simulation process. Therefore, the solution of quenching process with the latent heat is more difficult than that without the latent heat.

According to the characteristics of the quenching process, a high-speed data acquisition system based on industry standard architecture (ISA) port was designed in the paper. Using this system, the temperature variation of certain points in the sample can be acquired rapidly and accurately. A new method for estimating the temperature-dependent surface heat transfer coefficient in the quenching process was also presented. The finite element method (FEM), advance-retreat method and golden section method were respectively applied to solve the inverse heat conduction problem. The surface heat transfer coefficient was finally calculated according to the temperature curves gained by experiment.

Using the data acquisition system, the cooling curves of P20 steel quenched in 20 °C and 60 °C water were acquired, and the surface heat transfer coefficients were evaluated by using the methods presented in the paper. In the calculation process, the phase-transformation volume and the phase-transformation latent heat of every element were calculated by FEM. The temperature and the phase-transformation volume of every element were also calculated through the coupling calculation of phase-transformation latent heat.

2. Data acquisition system

The flow chart of the high-speed data acquisition system designed in the paper is shown in Fig. 1. It includes three thermocouples, two compensation cables, one amplitude modulation board, one ana-