Soft measurement model of ring’s dimensions for vertical hot ring rolling process using neural networks optimized by genetic algorithm

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Abstract: Vertical hot ring rolling (VHRR) process has the characteristics of nonlinearity, time-variation and being susceptible to disturbance. Furthermore, the ring’s growth is quite fast within a short time, and the rolled ring’s position is asymmetrical. All of these cause that the ring’s dimensions cannot be measured directly. Through analyzing the relationships among the dimensions of ring blanks, the positions of rolls and the ring’s inner and outer diameter, the soft measurement model of ring’s dimensions is established based on the radial basis function neural network (RBFNN). A mass of data samples are obtained from VHRR finite element (FE) simulations to train and test the soft measurement NN model, and the model’s structure parameters are deduced and optimized by genetic algorithm (GA). Finally, the soft measurement system of ring’s dimensions is established and validated by the VHRR experiments. The ring’s dimensions were measured artificially and calculated by the soft measurement NN model. The results show that the calculation values of GA-RBFNN model are close to the artificial measurement data. In addition, the calculation accuracy of GA-RBFNN model is higher than that of RBFNN model. The research results suggest that the soft measurement NN model has high precision and flexibility. The research can provide practical methods and theoretical guidance for the accurate measurement of VHRR process.

Key words: vertical hot ring rolling; dimension precision; soft measurement model; artificial neural network; genetic algorithm

1 Introduction

The medium-size rings whose diameter is less than 1000 mm, such as rail way bearing rings, spindle bearing rings and pipe flange rings, are the fundamental parts in modern industry. Vertical hot ring rolling (VHRR) process is the most effective forming technology for manufacturing these ring products [1−2]. Its working principle is shown in Fig. 1. The driving roll rotates around its axis and advances gradually toward the mandrel roll at a given feed rate; the mandrel roll is freely mounted, which rotates under the friction. Under the pressure between driving roll and mandrel roll, the ring’s diameter increases and the cross-section is formed [3−4]. The drive roll rotates around its own axis and moves toward the mandrel roll. The mandrel roll passively rotates around its fixed axis under the friction. The guide roll, which is used to maintain the ring rolling process stability, is also fixed in an appropriate place. The ring passes the gap between the drive roll and the mandrel roll, and the metal incremental plastic deformation occurs under the extrusion of the rolls, which cause the ring to shape the profile and expand the diameter, when the ring’s dimensions reach the required values, the feeding stops and the VHRR process finishes [1]. Up to now, a lot of research of radial-axial ring rolling process for large scale rings has been carried out [5], such as the theoretical analysis [6−7], macroscopic deformation rules [8] and equipment research [9]. These studies have promoted the rolling technology for the large scale rings. However, literature on VHRR process and its measurement and control method is relatively scarce. WANG and HUA [10] established the simple
VHRR measurement model based on the analytical and experimental method. However, the model is not suitable for the situation that the ring blank’s dimensions and the guide roll’s position are changed. In addition, the model cannot measure the ring’s inner diameter. On the basis of the studies mentioned above, this work aims at the practical issues of the actual VHRR production, analyze the relationships between the parameters of the ring blanks, the guide roll’s position, the displacement of the measuring roll and the ring’s dimensions, combined the finite element (FE) simulations and experiments of VHRR, establishes the soft measurement neural network (NN) model of the ring’s dimensions based on the radial basis function neural network (RBFNN). Finally, the verification experiments is conducted to tests the soft measurement model has high measurement precision and flexibility, the research conclusions can supply a new approach to the on-line measurement for VHRR process.

2 Soft measurement model of ring’s dimensions for VHRR based on RBFNN

Unlike the radial-axial large ring rolling process, there are no axial rolls on VHRR mill, and the ring’s axial deformation is restrained by the closed rolling pass [11]. The guide mode of VHRR process generally adopts single fixed guide roll, which results in the formed ring deviating from the symmetrical centerline of the drive roll and mandrel roll at the final rolling stage, as shown in Fig. 1. In addition, the rolling time of VHRR process is short (The rolling time of the ring product whose outer diameter is enlarged from 250 to 350 mm takes 4–6 s), the ring’s growth rate is fast and the position of the guide roll needs frequent adjustment. These factors leads the ring’s dimensions cannot be measured directly. Radial basis function neural network (RBFNN) has the advantages of simple structure, fast convergence rate and universal approximation [12]. It is suitable for modeling the nonlinear system. In this work, the RBFNN is utilized to establish the measurement model of the ring’s dimensions for VHRR.

2.1 Data sample acquisition of soft measurement NN model

The data sample obtained from VHRR experiment is limited. However, a mass of process data samples can be obtained from VHRR finite element (FE) simulation. So the VHRR FE models with different guide roll’s positions and different ring blanks are established and simulated in ABAQUAS software.

2.1.1 3D coupled thermo-mechanical FE model of VHRR

The 3D coupled thermo-mechanical FE model for VHRR, as shown in Fig. 2, is established according to the method proposed by WANG et al [13]. The contact pairs are defined between the ring and rollers. The friction and contact heat conduction exist at the interface of each contact pair. The rectangular section ring is considered as the subject investigated. The material of ring blank is bearing steel GCr15 and its true stress–strain behaviors with respect to different temperature curves are the same as those in Ref. [14]. The geometrical and movement parameters of VHRR FE models are summarized in Table 1. Reduced integration and hourglass control are employed to improve calculative efficiency and avoid the zero-energy mode, respectively. The adaptive mesh technology is adopted to control the distortion of the elements of the ring.

2.1.2 Data acquisition method of VHRR FE model

Least square circle method [13] is a common method to evaluate the rolled ring’s roundness. In FE model, a set of evenly spaced nodes are selected at the ring’s circumference, and several sensors are established in ABAQUAS to obtain the coordinates of the nodes during the simulation. The ABAQUAS/Explicit subroutine VUAMP of least square circle method is utilized and called at each time step. Then, the ring’s outer diameter,