Research on Internal Temperature Prediction of Slow Wave Structure Based on Experimental Data

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Abstract: At present, there are many researches on the thermal characteristics of traveling wave tube, but few researches and discussions on the measurement of its internal temperature field are involved. Moreover, it is difficult to monitor the internal temperature of traveling wave tube. In related research, an RBF neural network model based on ANSYS slow wave structure simulation data has been proposed. Data outside the slow wave structure is input into the model to calculate its internal thermal characteristics. On this basis, a simplified model of slow wave structure was designed in this study. The real data outside the model tube measured by the infrared temperature measurement system was input into the inversion model to get the internal temperature, and the error is small compared with the real internal temperature.

Keywords: Slow wave structure model, RBF neural network， Infrared temperature measurement

Introduction

The thermal performance of TWT slow wave structure is one of the factors that limit the average output power [1]. The thermal performance of slow wave structure will greatly affect the stability and reliability of TWT. In the previous study, we established the ANSYS simulation model of slow wave structure as shown in Figure 1, and obtained the temperature data outside and inside the tube by applying different heat flux density inside the tube.

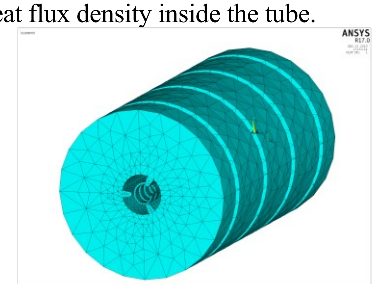


Figure 1. ANSYS simulation model of one slow wave structure

The RBF inversion model was trained by a part of simulation data, and the accuracy of the inversion model was verified by another part of simulation data [2].

TWT is in a vacuum sealed environment, the measurement of its internal temperature is almost difficult to complete, so it is almost impossible to use experimental data to verify the accuracy of the inversion model. In order to solve the problem, a simplified slow wave structure was designed. The internal and external temperatures of the simplified model were obtained by the infrared temperature measurement system. They were used to verify the accuracy of the inversion model established by ANSYS simulation data.

Method

The ANSYS simulation model of the simplified slow wave structure model is shown in Figure 2. The internal spiral-shaped resistance wire is closely attached to the copper tube, while an insulating material is passed in the middle. During the experiment, the resistance wire is heated continuously by electric current.

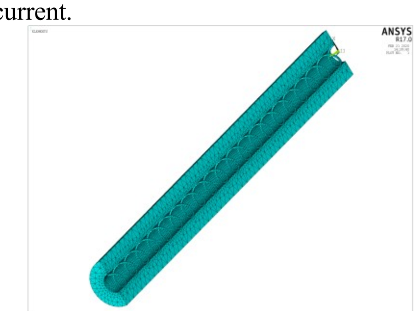


Figure 2. ANSYS model of simplified slow wave structure

RBF neural network is composed of input layer, hidden layer and output layer. The input layer is used to receive data; the hidden layer is a non-linear function that models the input data to achieve feature extraction; the output layer implements a linear combination of output weights [3].

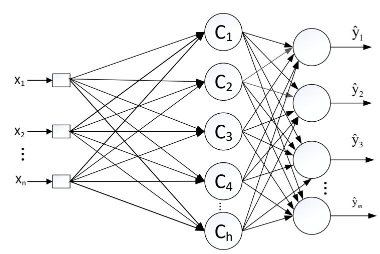


Figure 3. Schematic diagram of RBF neural network structure

In the RBF neural network model, the hidden layer is used as the core layer, and the node function is Gaussian when the input signal is passed to the hidden layer:

$$\varphi_j = (\|X_i - C_j\|) = \exp\left\{-\frac{\|X_i - C_j\|^2}{2\sigma_j^2}\right\} \tag{3}$$

Where $i = 1, 2, \ldots n$; $j = 1,2, \ldots, h$. X_i is the predicted variable; C_j is the center vector of the j-th Gaussian node in the hidden layer; σ_j is the width of the j-th neuron Gaussian function in the hidden layer; ||•|| is the Euclidean norm.

The output layer function is:

$$\hat{y}_t = \omega^T \phi = \omega_{1t}\varphi_1 + \omega_{2t}\varphi_2 + \ldots + \omega_{ht}\varphi_h \quad (4)$$

Where, $t=1,2,\ldots,m$; ω_{it} is the connection weight between the hidden layer and the output layer; $\hat{y}_t$ is the function output vector.

In order to quickly and accurately measure the temperatures inside and outside the tube, an infrared CCD camera is used to measure the outside and inside temperature of the simplified model [3].

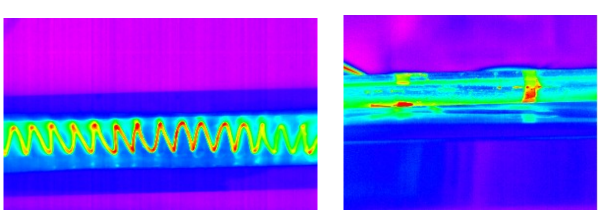
Any object can emit infrared thermal energy as long as its temperature is above absolute zero (-273°C)[4]. According to Stephen-Boltzmann's law, the radiated energy is as follows:

$$M = \sigma \times \varepsilon \times T^4 \quad (5)$$

Where T is the thermodynamic temperature of the object; M is the radiant energy; σ is the Stephen-Boltzmann constant; ε is the emissivity of the object, $\varepsilon \leqslant 1$. The infrared CCD camera converts the received radiant heat into the corresponding gray-scale signal, and obtains 640 * 512 pixels image [5].

Experiments and results

At first, the ambient temperature of the simplified simulation model of the ANSYS slow wave structure was set to 295K. After setting the corresponding thermodynamic parameters, the temperature values of the 8 points inside the simplified model tube and the 8 points outside the tube were obtained. A number of sets of temperature data can be obtained by setting different heat flux density. Then an RBF neural network inversion model is trained by these data. During the experiment, the internal helix is first heated by the electric current, and then the temperatures inside and outside the model is measured by the infrared temperature measurement system, as shown in Figure 4.



(a) (b)

Figure 4. Simplified model infrared temperature measurement results. (a). Infrared imaging inside the tube; (b) Infrared imaging outside the tube

The temperatures of 8 external points were substituted into the inversion model trained by simulation data, and 8 predicted internal temperatures were output, which were compared with the actual internal temperature to verify the accuracy of RBF inversion model. Forty groups of real data were selected during the experiment. The temperature error rate of the eight positions inside the simplified model was shown in Figure 5, where the horizontal axis represents the time of the experiment and the vertical axis represents the error rate.

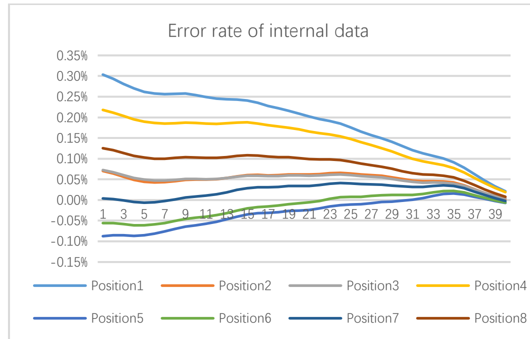


Figure 5. Error rate of real data inversion results

It can be found that the error rate is relatively low, all below 1%, which proves the reliability of the inversion model. In the later research, the simplified model which is more complex and closer to the real slow wave structure model will be designed to verify the reliability of the inversion model.

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