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Research paper

Effects of the porous media distribution on the performance improvement for isothermal chamber

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HIGHLIGHTS

- Change the distribution of copper wire can improve the isothermal performance.
- The copper wire in the isothermal chamber was layered filling.
- The porosity must decrease gradually from the center to the container wall.

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ABSTRACT

In order to improve the isothermal performance of isothermal chamber, how the distribution of thin copper wire on chamber cross-section enhances the heat transfer from wall to center was studied in this paper. Firstly, the heat conduction model was established and the temperature fields and the center temperature were calculated under the condition of the copper wire was stuffed uniformly. Secondly, under the circumstance that the temperature of chamber wall, the average stuffed density of copper wire and initial temperature in the center were certain, taking the maximum of center temperature as the optimization objective after heat conduction lasting 15 s, the variable density method and the adaptive growth method were used respectively to optimize the distribution of copper wire in order to enhance the heat conduction from the chamber wall to the center. Compared with the uniformly filling, the results of the center temperature were increased 4.94% and 16.50% respectively. Moreover the corresponding copper wire porosity distribution curves were obtained. Finally, the copper wire in the isothermal chamber was layered filled based on the optimized results. Then the verification experiments and verification simulation were carried out to verify that change the distribution of copper wire could enhance the heat conduction from the wall to center. Moreover, according to the results of discharging experiments for isothermal chamber, it was verified that the filling scheme could improve the isothermal performance of isothermal chamber.

1. Introduction

Isothermal process is a process of ideal gas state change in pneumatic system. By filling fine wire to form isothermal container is currently the only method which can realize approximate isothermal in the pneumatic system. Isothermal chamber is used in the testing and control of pneumatic system, its temperature characteristic is co-influenced by the filling quantity of metal wire and the mass flow of compressed air, and is directly related to the testing and control precision [1]. Cai [2] introduced the working principle and wide application of the isothermal chamber in detail. Many scholars regard the fine metal wire as porous media when they study on the heat transfer enhancement [3,4]. Yang [5] did a numerical simulation during discharge for isothermal chamber filled with fine copper wire of 0.3 kg/L. Based on the temperature field at the end of discharging, it can be seen that the largest temperature difference is between the chamber wall and the center of chamber. During isothermal chamber discharge, the air temperature in the chamber must decrease for the pressure decrease, and the chamber wall is the main heat resource. Therefore, in order to improve the isothermal temperature performance of isothermal chamber, it must strengthen the heat conduction from the chamber wall to the center and narrow down the temperature difference between the wall and the center.

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Table 1
Calculation results contrast between Matlab and Ansys.

Elapsed time(s)	10	15	20	30	40	50	60
The temperature at $r = 4$ mm by Matlab °C	20.1241	20.8641	22.3573	26.5001	30.7568	34.4676	37.5316
The temperature at$r = 4$ mm by Ansys °C	20.3134	21.1544	22.9569	27.5886	32.0727	35.8336	38.8590

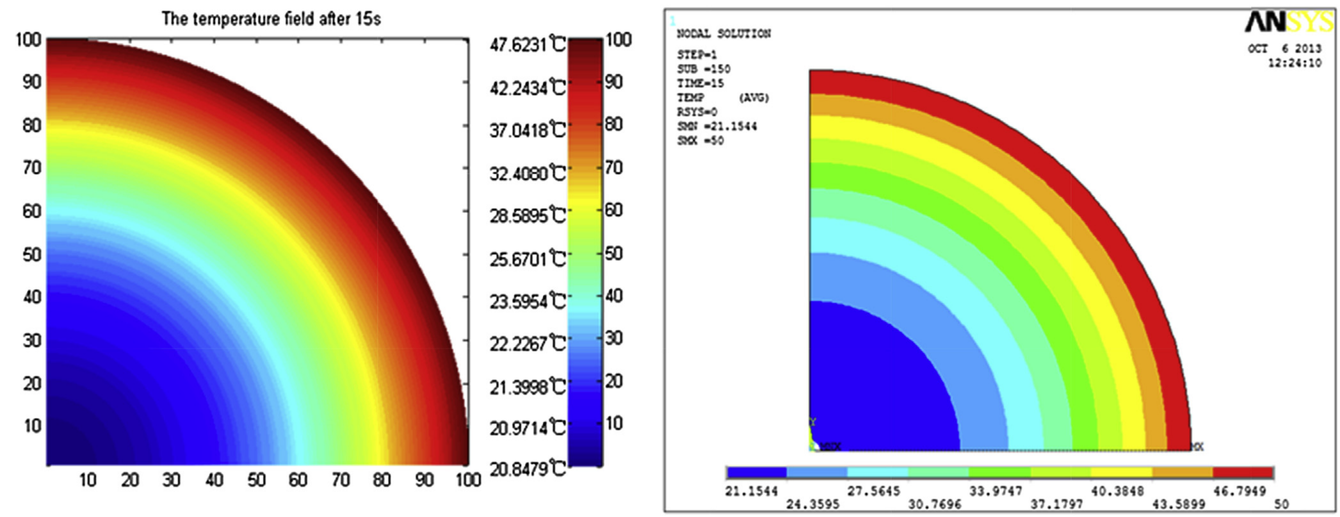

Fig. 1. Temperature fields of Matlab (left) and Ansys (right).

Optimization of heat conduction structures is a significant research field, which is filling a certain volume of high thermal conductive materials to a fixed area, so as to get the optimal heat transfer path structure. Zuo [6] established topology optimization mathematical model of heat conduction structure by the variable density method in structural mechanics. It shows that the topology optimization methods which are widely used in structural optimization can also be used to optimize topological distribution of material to strengthen heat transfer. An isogeometric shape sensitivity analysis method is developed for heat conduction problems using the adjoint variable method [7]. Jeong [8] proposed an enhanced model in LED module to achieve effective heat dissipation. Lim [9] studied on the design optimization of a tubular solar receiver with a porous medium and found the optimal design point of the proposed solar receiver concept to heat up compressed air. Some scholars studied the related problems of heat conduction structure model on the basis of variable density method. Sun [10] optimized the distribution of copper wire in the isothermal chamber by variable density filling method with two and three floors.

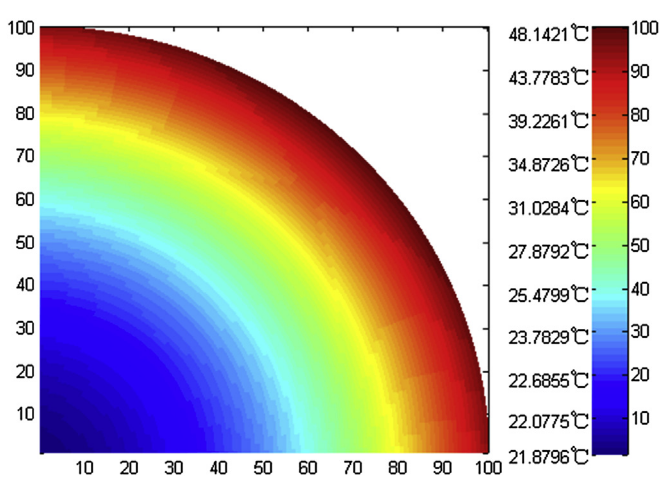

Fig. 2. Temperature field based on variable density method.

Currently, isothermal chamber is filled uniformly with fine copper wire. With the increase of the filled wire volume, isothermal effect is improved, but not significant [11]. However, the more copper wire will increase the cost. In this paper, the variable density method and the adaptive growth method were applied to vary the copper wire distribution in order to enhance heat conduction of porous media in isothermal chamber and the filling rule about the distribution of copper wire was concluded. Applied this filling rule to form the isothermal chamber, the isothermal performance of isothermal chamber was improved.

2. Heat conduction model in cross-section of isothermal chamber

2.1. Heat conduction model for isothermal chamber

The cross section of isothermal chamber is a circle with the diameter of 200 mm. To facilitate the research, a quarter of the circle, the fan of which the central Angle is 90°, was selected.

Due to the fact that the research object was a fan, thus here the unsteady heat conduction equation under polar coordinate was chosen [12].

$$\rho c\left(\frac{\partial T}{\partial t}\right) = \frac{1}{r}\frac{\partial}{\partial r}\left(r\lambda\frac{\partial T}{\partial r}\right) + \frac{1}{r}\frac{\partial}{\partial \theta}\left(\frac{\lambda}{r}\frac{\partial T}{\partial \theta}\right) \tag{1}$$

Where λ is heat conductivity coefficient of materials, W/(m·K); ρ is density of materials, kg/m^3; c is specific heat capacity of materials, J/($kg \cdot K$).

As for filled large porosity copper wire, the corresponding thermal conductivity coefficient, density, and specific heat capacity are obtained by the following formulae.