Topology Optimization and Material Selection of Cooling Fin Structure in Submarine Data Center

Guancheng Hao 1a*, Jianxiang Jin2b*, Chenghao Zhong 3c
1 Department of Vehicle Engineering Shenyang Aerospace University, Shenyang 110136, China
2 Department of Energy and Power Engineering Shenyang Aerospace University, Shenyang 110136, China
3 Department of Aircraft Power Engineering Shenyang Aerospace University, Shenyang 110136, China
a*1255815019@qq.com, b*1427407830@qq.com, c21490496003@qq.com

Abstract—The optimization of fin heat dissipation structure has always been an interesting topic, and a good heat dissipation structure is conducive to the full function of electronic devices. In order to obtain the best heat dissipation structure, the COMSOL density penalty method and heat conduction model are adopted to study the topology optimization model of heat dissipation structure. On the basis of circular fins, the material types of fins are kept unchanged, and the optimized fins are obtained after topology optimization under various working conditions. The contact area and average temperature of the topological fin and circular fin are compared. The simulation results show that the topology fin has better heat dissipation performance when the heat source power and ambient temperature are similar. Compared with the circular fin profile, the contact length of the topological fin increases by 48%, and the average temperature is reduced by 14.7K. After obtaining the best heat dissipation structure, the entropy weight method is adopted to select the best heat dissipation material of heat dissipation fins and determine that the best heat dissipation material is lead.

1. Introduction
The cost of energy consumption in global data centers is huge, especially the energy consumed by electronic devices for heat dissipation. Big data centers in various countries will set up submarine data centers to reduce the temperature of servers by absorbing heat from seawater. In order to improve the heat dissipation performance of the container, a ring-shaped fin structure is installed on the outer shell. Ring-shaped fins are widely used because of their simple structure, mature manufacturing technology and low price. The structure of fins has an important influence on its heat dissipation performance. At present, the research on fins mainly focuses on three aspects: fin thickness, fin spacing, and fin height [1-2]. The optimization of fin heat dissipation structure can use the topology optimization method, the mathematical method of optimizing the material distribution in a given area according to the given load, constraint conditions, and performance indexes. Liu Shutian and others established the topology optimization model of heat dissipation structure [3]. You Hao and others carried out topology optimization on the structure of air-cooled straight fins and studied the topology optimization model with the minimum heat dissipation weak fire product as the objective function [4]. Wang Hongwei simulated the heat dissipation structure numerically and put forward the selection method of the best
heat dissipation material [5]. At present, the research mainly focuses on the fin profile but less on the longitudinal section. The research on the longitudinal section of fins will help to further improve the heat dissipation performance of containers and give full play to the functions of electronic devices.

In this paper, based on the enhanced heat transfer of laminar flow under natural convection background, the shape of the annular fin is optimized by the topological optimization method. In the process of optimization, the shape of the fin profile changes without changing the material of the fin to improve the heat dissipation performance of the fin and reduce the average temperature of the heat-dissipating container. After obtaining the best heat dissipation structure, the entropy weight method is used to select the fin material.

2. Topology optimization of the preset structure

2.1. optimization model of natural convection fins

The main way of fin heat dissipation is heat conduction. Under the background of enhanced heat dissipation, it can be regarded as the spatial distribution of fin material with larger thermal conductivity and water with smaller thermal conductivity. The optimization process should satisfy the heat balance equation:

\[-\nabla [k(x)\nabla T] + h(T - T_a) = Q\] (1)

Where \(Q\) is the internal heat source term; \(h\) is the surface heat transfer coefficient of convective heat transfer; \(T_a\) is the ambient temperature; \(T\) is the fin temperature.

\[k(x) = (0.001 + 0.999x^u)k_0\] (2)

Where \(u\) is the penalty coefficient, take 3; \(k_0\) is the thermal conductivity of the thermally conductive material.

The objective function is the average temperature of fins, and the fin has the best heat dissipation performance when the objective function is the smallest. Mathematical model [4-6] can be expressed as:

\[\min f_G(X) = \left( \frac{1}{|\Omega|} \sum_{i=1}^{N} \int_{\Omega_i} \left(N_iT_i\right)^n d\Omega_i \right)^{1/a}\] (4)

s.t. \(V = \sum_{i=1}^{e} x_iV_i \leq qV_0\) (5)
\(P = kT\) (6)
\(0 < x_{\min} \leq x_m \leq x_{\max}\) (7)

Where is the temperature vector of each node; \(P\) is the node thermal load vector; \(k\) is the thermal stiffness matrix; \(V\) is the total volume of the optimized heat transfer structure; \(V_i\) is the volume of the \(i\)-th unit; \(e\) is the total number of units; \(q\) is the volume constraint factor; \(V_0\) is the initial volume; \(G\) represents the average temperature of the fins; \(x_{\max}\) and \(x_{\min}\) is the upper limit and lower limit of the design variable respectively; \(\Omega_i\) represents the fin area; \(n\) is the coagulation factor; \(|\Omega_i|\) represents the area of the fin area; \(N_i, T_i, \Omega_i\) are the shape function matrix, node temperature array, and region of the \(i\)-th element, respectively.

3. Two-dimensional topology optimization calculation and discussion

3.1. structure setting

In the laminar forced heat exchange structure, the heat generated by the heat source diffuses into the water through the annular fins, so the fin profile design is very important. In topology optimization, only
one channel is analysed because of the similar structure of parallel channels, as shown by the dashed box in Figure 1(b). When the radiator container is in water, the container's heat will be reduced when the water flow on either side acts on the fins at a certain speed. In order to get more accurate topology optimization results, this paper optimizes the fins under two working conditions. The two working conditions are that the water flow acts on the fins from the left side and the flow on the fins from the right side, as shown in Figure 1(a).

![Structural model](image)

(a) structural model

![Topology optimization calculation area](image)

(b) Topology optimization calculation area

![Schematic diagram of a closed container](image)

(c) Schematic diagram of a closed container

Fig. 1 Fin model drawing

Set the height of the water flow area to 5 mm and the width to 50 mm; The outer diameter of the fin is 4 mm, and the inner diameter of the fin is 1.6 mm. The power of the uniform heat source in the concentric ring of fins is 2.5W. The ambient temperature $T_a$ of the heat dissipation structure is defined as 20℃. The copper sheet with high thermal conductivity is pre-selected in the fin area, and its thermal conductivity is 400 W/(m·k). The filtering radius is 0.1 mm. After the optimized mathematical model is obtained, the optimal design variables are solved by the optimization algorithm. Using the MMA method, the objective function is stable after 80 iterations. Results After treatment, the distribution of fin materials in space, that is, the optimal structure of fin heat dissipation was obtained.

3.2. Topology optimization results and discussion

Topology optimization is carried out by setting the above model. After 80 iterations, the optimized fins are obtained. As shown in Figure 2, the final temperatures of circular fins and topological fins are compared. As can be seen from Figure 2, compared with circular fins, topological fins are more conducive to leading out the heat of fins when water flows in on either side, and the convection heat exchange area on the right side of fins generates outward expanding branches, which increases the heat dissipation area and makes the heat source more fully utilize the low-speed fluid for heat transfer; The optimized numerical value of fin structure is shown in Table 1. The results show that the average temperature of the heat source decreases by 14.7K, the contact length of topological fins is longer than that of circular fins, and the heat exchange capacity is better.
4. Evaluation and selection of container material attributes

4.1. Comprehensive evaluation model
According to 61 kinds of materials and their physical parameters, Evans and Robinson establish a comprehensive evaluation model [7-8]. According to the functional classification of each material, the materials with higher extended attributes and moderate prices in the same category are selected in the container manufacturing process to obtain the container with the lowest total cost and the best performance. The index system is a comprehensive index with six indexes, and the target layer aims at evaluating container materials. It is first necessary to determine the weight coefficient of each index in the comprehensive evaluation process. The weight coefficient is used to measure the importance of the index in the model, and the weight coefficient refers to the numerical value that plays a role in weighing the target value in a field. The method to determine the weight is divided into subjective weight method and objective weight method two categories, including subjective weight method such as Delphi method, AHP method, expert grading method; Objective weight assignment methods include standard deviation method and entropy weight method. Etc. Subjective weight methods include entropy weight method, standard deviation method, CRITIC method, TOPSIS method, rank-sum ratio method, etc. The subjective weighting method has the defect of strong subjectivity, which often reduces the validity and scientificity of calculation results. Therefore, we need to select the indicators needed by the model based on the experience of experts and then use a more objective method to distribute the weights to avoid the errors caused by human factors and fully make the data speak. Therefore, objective weighting is our first choice. Considering the simplicity and accuracy of the objective weight solution, this paper uses the entropy weight method to determine the weight.

According to the concept and characteristics of information entropy, The degree of randomness and disorder can be measured by entropy. We can also judge the dispersion degree of an index by entropy value. The dispersion of the indicators was positively correlated with the impact of the comprehensive evaluation.

4.2. Result analysis
The data information of each material is obtained by statistics of the data in the attachment, and the obtained data is substituted into the entropy weight model and solved by MATLAB to obtain the weight of each index as shown in the following table:

| type           | Average temperature /K | Contact length /mm |
|----------------|-------------------------|--------------------|
| Circular fin   | 338.86                  | 12.57              |
| Topological fin| 324.16                  | 18.60              |

Fig. 2 Temperature and structure diagram before and after optimization

Table 1. Comparison before and after optimization
Table 2. Material Attribute Weight

| index         | Index weight |
|---------------|--------------|
| density       | 0.0592       |
| modulus of elasticity | 0.2724       |
| yield strength | 0.2359       |
| tensile strength | 0.2406      |
| potential     | 0.0284       |
| corrosivity   | 0.2819       |

The results are as follows:

Table 3. Comprehensive attribute results

| sort | material                          | Comprehensive attribute value |
|------|-----------------------------------|-------------------------------|
| one  | lead                             | 0.028281                      |
| 2    | zinc (Zn)                        | 0.042655                      |
| three| 303 stainless steel              | 0.091290                      |
| four | 32 stainless steel               | 0.080764                      |
| five | aluminum alloy                   | 0.057536                      |
| six  | Martensitic aging 300 steel      | 0.124742                      |
| ...  | ...                               | ...                           |
| 60   | gold                             | 0.071601                      |
| 61   | Industrial pure magnesium        | 0.039605                      |

According to the table analysis, the comprehensive properties of each material are quite different. Therefore, the materials with higher comprehensive properties and moderate prices in the same category are selected in container manufacturing to obtain the container with the lowest total cost and the best performance.

Visualize the data. The following figure shows the physical parameters and total attribute values of each material:

Fig. 3 Physical parameters of materials          Fig. 4 Comprehensive property values of materials

We can get that the best material is lead, and the comprehensive attribute value is 0.028281.

5. Conclusion:
Under the condition of keeping the material types of fins unchanged, the fins are optimized under two working conditions by the method of topology optimization. When the heat source power and ambient
temperature are the same, the heat dissipation performance of topological fins is better. The main conclusions are summarized as follows:

1. The fin obtained by topology optimization has a larger contact area and lower average temperature. Compared with circular fins, the contact length of topological fins increases by 48%, and the average temperature decreases by 14.7k.

2. The entropy weight method is used to determine the weight, and finally, the best material is lead.

3. This paper provides a method to improve the heat dissipation capacity of fins, which is of great significance to the heat dissipation of submarine server containers. In terms of future work, we should further study the influence of the optimized fin thickness and spacing on the heat dissipation performance of the container to further reduce the working temperature of electronic devices.

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