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Optimization model of container heat dissipation based on submarine data center

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Abstract: Based on the heat dissipation principle of solid in liquid, this paper studies the heat dissipation of submarine data center container, and gives the design scheme of submarine data center container shell, which provides a strong theoretical basis for reducing the energy loss of data center. According to the heat dissipation principle of solid in liquid, the physical model of convective heat transfer between container and seawater is established, and the convective heat transfer coefficients under different conditions are analyzed.Using Newton's cooling law, an integer programming model is established to maximize the heat dissipation effect.Finally, the maximum number of servers in a single container shell is obtained by solving the integer programming problem.

1. The Establishment and Solution of Model

1.1 Model preparation and analysis

Using MATLAB to solve, select the side circle and place it in the direction of the width and height of the server, and the maximum number of servers is 484.

Ignoring the influence of variables such as seawater depth that have no or negligible influence on the container, the seawater flow is stable, the heat dissipation is uniform (it is regarded as an isothermal plate), and the problem of thermal boundary layer is not considered.There will be both forced convection heat transfer and natural convection heat transfer between container and seawater, that is, mixed AC heat transfer.

1.2 Establishment of integer programming model

1. Establishment of objective function

To evaluate the maximum number of servers that can be placed in a single container shell, set the number of servers in the data center as x Set up the objective function as follows:

$$max=x \tag{1}$$

max is the maximum number of servers.

2. Establishment of constraints

(1) Under the condition that only the volume relationship between container and server is considered, the maximum number of servers is 484;

(2) The heat dissipation of the server shall meet Newton cooling law:

$$\begin{cases} \Delta t = \left|t_w - t_f\right| \\ q = h\,\Delta t \\ \phi = qA = Ah\Delta t = \frac{\Delta t}{1/hA} \end{cases} \tag{2}$$

Of which:q is the heat flux density,h is the convective heat transfer coefficient of the material,ϕ is the heat transfer power (also known as heat flow and heat transfer rate),A is the heat transfer area.

Therefore, the constraints are as follows:

$$\begin{cases} 0 \le x \le x\_max \\ \frac{\phi \cdot x}{hA} \le \Delta t \end{cases} \tag{3}$$

Of which:$\Phi = 500\text{w}$, which is the heat generation power of a single server;

$\Delta t = 80℃ - 20℃ = 60℃$, the normal operating temperature difference of the server.

3. Solution of integer programming model

Lingo is used to solve the integer programming problem. Under the condition of only considering the heat dissipation demand of the server, it is concluded that up to 484 servers can be placed in a single container shell.

1.3 Model optimization

Fin is a kind of heat transfer element, which is used to expand the heat exchange area and improve the heat dissipation efficiency.It can be seen from reference [1] that when the ambient temperature is constant, the spacing between fins $r = 0.022m$ the heat dissipation effect is the best.

1.3.1. Flat fin structure based on cylinder

1. Construct objective function

Considering the common flat fin structure, in order to increase the surface area of the container, the bottom surface of each row of fins is continuously distributed on the cylindrical surface. Therefore, the corresponding objective function is as follows:

$$max = 2\pi d^2 + 24\pi d + 2ab \cdot x_1 \cdot x_2 \tag{4}$$

Of which:

a--Width of single fin, b--Length of single fin ($b = \frac{D-2d}{2}$), x_1--Number of turns of fins placed laterally in the data center enclosure ($x_1 = [\frac{Length}{r}] + 1$), x_2 --Total number of fins placed longitudinally around the side circle of the container in the data center shell.

2. Establish constraints

According to the fin structurex_2 the width of each fin shall be equal to the circumference of the side circle of the container, i.e. with the following constraints:

$$ax_2 = 2\pi d \tag{5}$$

According to equations (4) and (5), the maximum surface area of the data center after adding the cross flat fin structure can be calculated.

3. Objective function solution

Lingo can calculate that the maximum surface area of the flat fin structure based on the cylinder is $69.75771m^2$

1.3.2 Circular fin structure based on cylinder

1. Construct objective function

It can be seen from the flat fin structure of the fork row discussed above that when the single fins of each circle are put together to form a ring, the surface area of the data center shell is larger than that before, which is more conducive to heat dissipation.The corresponding objective function is expressed as follows:

$$max = 2\pi d^2 + 24\pi d + 2x_1\left[\pi \cdot \left(\frac{1}{2}\right)^2 - \pi d^2\right] \tag{6}$$

2. Objective function solution

According to equation (6), lingo can calculate that the maximum surface area of circular fin structure based on cylinder is $70.07941m^2$.

1.3.3 Square fin structure based on cylinder

1. Construct objective function

$$max = 2\pi d^2 + 24\pi d + 2x_1[1 - \pi d^2] \tag{7}$$

2. Objective function solution

According to equation (7), lingo can calculate that the maximum surface area of the square fin structure based on the cylinder is $304.6197m^2$.

1.3.4 "Coral saddle fin" structure based on cuboid

1. Determine the maximum number of servers contained in the box container

When the length of the server is parallel to the length of the box, the corresponding functional relationship is:

$$max = x_1 \cdot x_2 \cdot x_3 \tag{8}$$

Establish the following constraints:

$$\begin{cases} L_1 \cdot x_1 \leq Length; \\ L_2 \cdot x_2 \leq Width; \\ L_3 \cdot x_3 \leq Height; \\ L_1 \cdot L_2 \cdot L_3 \cdot x_1 \cdot x_2 \cdot x_3 \leq Length \cdot Width \cdot Height. \end{cases} \tag{9}$$

Calculated by lingo, the cuboid data center can accommodate up to 968 servers.

2. Construct objective function

The surface area of the new shell structure is calculated by the overall method

$$max = Length \cdot Height \times 4 + 2Width \cdot Height - t \cdot m \cdot (n_1 - 1) \times 2 + Width \cdot m \cdot (n_1 - 1) \times 2$$

$$n_1 = 22, n_2 = 2, n_3 = 22, t = \frac{Length - n_1 \cdot L_1}{n_1 - 1}, \quad m = n_3 \cdot L_3 \tag{10}$$

3. Objective function solution

Using lingo, the maximum surface area of the cuboid based "coral saddle surface fin structure can be calculated as $77.4m^2$.

1.3.5 "Coral saddle fin" structure based on cylinder

1. Establish objective function

The surface area of the new shell structure is calculated by the overall method

$$max = Length \cdot \pi \cdot D + 2\pi\left(\frac{D}{2}\right)^2 - t \cdot \pi \cdot (2\pi - 4o) \cdot \frac{n_1 - 1}{2\pi} + \frac{\pi - 20}{2\pi} \cdot \pi \cdot \frac{1}{4} - \sqrt{\left(\frac{1}{4} - \left(\frac{1}{2} - L\right)^3\right.} \times (n_1 - 1) \times 4$$

$$n_1 = 22, n_2 = 2, n_3 = 22, t = \frac{Length - n_1 \cdot L_1}{n_1 - 1}, m\text{--}\ m = n_3 \cdot L_3, o\text{--}\ o = \arcsin\frac{\frac{1}{2} - L}{1/2} \quad (11)$$

2. Objective function solution

Lingo can calculate that the maximum surface area of the "coral saddle fin" structure based on the cylinder is $66.81539m^2$.

1.3.6 Comparison of different container structures

Table 1

Fin Type	**Number of servers**	**Container surface area(m^2)**
Cylinder based straightness fin structure	484	69.75771
Cylinder based torus fin structure	484	70.07941
Square based on cylinder fin structure	484	304.6197
Box based coral-Saddle fin structure	968	77.40000
Cylinder based coral-Saddle fin structure	484	66.81539

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