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Design of one-dimensional heat conduction model for thin-walled fin in submarine data center

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Abstract: In recent years, due to the rapid growth of big data center in coastal cities, and the high cost of land construction, occupying more land, cooling consumes a lot of power and cold water resources, causing a prominent resource contradiction, thus the undersea data center project came into being. "Undersea data center project" does not occupy or rarely occupies land resources, saves energy consumption, does not need fresh water consumption, and can greatly shorten the distance between data and users, and has the characteristics of low cost, low delay, high reliability and high security, so as to realize the green and sustainable development of big data center. However, the project is a new project, there are still many areas to be improved. How to design the container shell structure for heat dissipation is a very worthy of discussion. Firstly, we determine the geometry of the container by comparing the surface area of the cuboid and the cylinder under the same volume; Then, in order to ensure more sufficient heat dissipation conditions, we consider increasing the surface area of heat dissipation by adding fins. A one-dimensional heat conduction model of thin-walled fin is established. Under different thermal conductivity conditions, rectangular fin, triangular fin or parabolic fin are arranged. Finally, we designed the overall shape of the container and select the material of the shell to ensure the best heat dissipation effect.

1. Introduction

According to statistics, the annual power consumption of global data centers accounts for about 2% of the global total power consumption, in which the cost of energy consumption accounts for 30%- 50% of the whole IT industry, and the heat dissipation of electronic devices accounts for a large proportion of the energy consumption.In recent years, due to the rapid growth of big data center in coastal cities, and the high cost of land construction, occupying more land, cooling consumes a lot of power and cold water resources, leading to a prominent resource contradiction.

"Undersea data center project" is to serve each other with offshore wind power, offshore oil and other industries, deploy in coastal urban waters, shorten the distance between data and users, and install Internet facilities such as servers in undersea closed pressure vessels with advanced cooling function, use undersea composite cable for power supply, and conduct heat exchange with a large amount of flowing seawater, It is a project to cool Internet facilities and send data back to the Internet. It does not occupy land resources, saves energy consumption and does not need fresh water consumption to achieve green and sustainable development of big data center. In 2015, Microsoft tested the "undersea data center project" in a sea area of the United States, and found that its failure rate was 1 / 8 of that on land. In 021, China's first undersea data warehouse was built, marking that China's big data center entered the marine era.

For the undersea data center, how to improve the heat dissipation intensity is an urgent problem. Based on the determination of the maximum size of the container and the seabed environment, we design the shell structure of the container to achieve the best heat dissipation effect.

On the other hand, the deeper the sea water is, the lower the temperature is, the better the heat dissipation effect is, and the greater the pressure on the container shell is, because all kinds of metals are subject to metal corrosion, so on the basis of ensuring the maximum heat dissipation efficiency of the container structure, reducing the cost as much as possible, improving the service life, and selecting the appropriate materials and seabed depth for optimization.

Then, considering the influence of seasons and tides on the construction of the data center? Through the establishment of mathematical model analysis, we should consider the impact of tides on the construction of the data center, not the impact of seasonal changes on water temperature.

2. Model Establishment and Solution

2.1 Fluid Water Pressure Model

In the sea water, the shape of the container in addition to considering the heat dissipation efficiency, the sea water pressure is also a factor that can not be ignored. Considering the storage of servers as much as possible and the stability of containers in seawater, we analyze two commonly used shapes and add fins to maximize the heat dissipation effect. In this problem, the maximum size of the container has been given, and the maximum volume has been fixed, and the water pressure is the same. Therefore, we only need to analyze the same volume of cylinder and cuboid whose surface area is large.

The container is subjected to water pressure in seawater:

$$P = \rho g h \tag{1}$$

Pressure on containers:

$$F = P\ S \tag{2}$$

$$S_1 - S_2 = 2(ab + ac + bc) - 2\pi r(r + a) = 2\ a\ r[(2\pi)^{\frac{1}{2}} - \pi] > 0 \tag{3}$$

S_1 represents the surface area of the cuboid, S_2 represents the surface area of the cylinder. From the above formula and calculation, it can be concluded that under the same volume, the surface area of the cylinder is smaller, the pressure of water is smaller, and the overall efficiency is higher. Therefore, we choose the cylinder as the basic container structure. After determining the structure of the container, in order to maximize the heat dissipation effect, we choose to add fins to assist the heat dissipation. The common fin structures are straight fin, louver fin, serrated fin, porous fin and corrugated fin. By analyzing the structure of the fins and their transfer efficiency between solid, gas and liquid, we find that the heat dissipation efficiency is higher by adding flat fins on the cylinder.Straight fins are divided into parabola, triangle and rectangle, which are analyzed in the following.

2.2 One Dimensional Heat Conduction Model of Thin-walled Fin

The surface with fins can establish an enhanced heat transfer mechanism between the original surface and the surrounding medium, so it is widely used in the enhanced heat transfer process of various devices, and plays an important role in the design of thermal system. The optimal design of the fin has always been paid attention to by designers. Flat fin is a kind of extended surface with simple manufacture and low cost, which is commonly used in all kinds of computer CPU, electronic and electrical equipment, engine cooling system. Based on the one-dimensional heat conduction model, the rectangular, triangular and parabolic fins with different cross sections are analyzed under certain assumptions and model simplification, and their heat dissipation capacity under different conditions is compared.

$$\frac{d^2T}{dx^2}+\left(\frac{1}{A_c}\times\frac{dA_c}{dx}\right)\frac{dT}{dx}-\left(\frac{1}{A_c}\times\frac{h}{k}\times\frac{dA_s}{dx}\right)(T-T_t)=0 \tag{4}$$

Where: $T=T(X)$, A_c、A_s as represent the side surface area and cross-sectional area from the fin base to a certain section respectively.

According to the law of conservation of energy, the convective heat transfer rate on the fin surface must be equal to the heat transfer rate through the fin substrate. Therefore, the heat dissipation rate of the whole fin is expressed as

$$q_f=h[T(x)-T_l]dA_s=h\theta(x)dA_s \tag{5}$$

In addition, in order to conveniently characterize the performance of a certain fin, a parameter: fin efficiency is usually used η, It is defined as follows:

$$\eta_f=\frac{q_f}{hA_f\theta_b} \tag{6}$$

θ_b is the fin base temperature.

Therefore, the expression of fin heat dissipation rate can also be written as follows:

$$q_f=hA_f\theta_b\eta_f \tag{7}$$

According to the relevant parameters, the heat dissipation rate equation can be written as:

$$q_{r\theta c}=\sqrt{2hkwt(w+t)}-\left\{\frac{sinh\left[\sqrt{\frac{2h(w+t)}{kwt}}-L\right]+\sqrt{\frac{hwt}{k(w+t)}}cosh\left[\sqrt{\frac{2h(w+t)}{kwt}}-L\right]}{cosh\left[\sqrt{\frac{2h(w+t)}{kwt}}-L\right]+\sqrt{\frac{hwt}{k(w+t)}}sinh\left[\sqrt{\frac{2h(w+t)}{kwt}}-L\right]}\right\}=\theta_b \tag{8}$$

$$q_{tri}=\sqrt{\frac{bkt}{2}}-\left(\frac{w\sqrt{t^2+4L^2}}{L}+t\right)-\frac{l_1(2L-\sqrt{\frac{2h}{kt}})}{l_0(2L-\sqrt{\frac{2h}{kt}})}-\theta_b \tag{9}$$

$$q_{p\delta r}=h\left[w-\left(\sqrt{t^2+L^2}+\frac{L^2}{t}ln\frac{\sqrt{t^2+L^2}+t}{L}\right)+\frac{2}{3}-Lt\right]+\frac{2}{\left[\frac{8hL^2}{kt}+1\right]^{\frac{1}{2}}+1}-\theta_b \tag{10}$$

2.3 The Solution of the Model

Given basic parameters: w=70mm, t=1mm, $t_b=50°C, t_1=\frac{250\ w}{m\ k}$, h is the variable,we can draw a conclusion.

When h is in the range of $0-26w/(m^2-K)$, the heat dissipation efficiency of the three is $q_{par}>q_{trl}>q_{rec}$

When h is in the range of $26-119w/(m^2-K)$, the heat dissipation efficiency of the three is $q_{trl}>q_{par}>q_{rec}$

When h is in the range of $119-148w/(m^2-K)$, the heat dissipation efficiency of the three is

$q_{trl} > q_{rec} > q_{par}$

H is the heat transfer coefficient. Different container materials have different heat transfer coefficients, and the optimal flat fin type is also different. The large structure of the container shell designed by us is cylinder, and the corresponding flat fin type is added according to the range of heat transfer coefficient of different materials.

2.4 Material Selection of Container Shell

We all know that the deeper the sea water is, the lower the temperature is, the better the cooling effect is. Although we have found the structure of the container shell that can maximize the heat dissipation effect, the deeper the sea water is, the greater the pressure on the container shell structure by sea water is, and the corrosion of sea water on the shell will affect the heat dissipation efficiency, Therefore, it is necessary to select the appropriate metal materials and depth for optimization, which can not only improve the compression capacity of the container shell, resist seawater corrosion, reduce the material cost and improve the service life, but also maximize the thermal power.

Because there are many types of materials and their properties are not the same, we can take the contact with seawater, the cost, the water absorption, the strength of corrosion resistance as the basis for the preliminary screening of materials. Further quantitative analysis of each performance of the selected materials. The principal factor analysis model can classify the same essential variables into one component, reduce the number of variables, and test the hypothesis of the relationship between variables. Finally, the principal factor analysis model can be established to analyze the selected metal materials, find out the hidden representative components, and determine the most suitable metal materials.

Factor analysis can find out the hidden representative components in many variables. It can reduce the number of variables and test the hypothesis of the relationship between variables by classifying the same essential variables into one component. The steps of establishing and solving the model are as follows

The first step is to establish the coefficient matrix according to the relevant data collected in the previous step.

The second step is to transform the coefficient matrix into a standardized matrix.

The third step is to calculate the correlation coefficient matrix for the standardized matrix X.

The fourth step is to solve the characteristic equation of the correlation matrix R and the corresponding eigenvector U

The fifth step is to select a principal component and calculate the comprehensive evaluation value.

According to the characteristic value and contribution rate, we selected four materials with better comprehensive properties: AISI 1080 steel, 302 stainless steel, HY-100 steel and AISI 1040 steel.

We choose AISI 1080 steel. According to the yield strength, tensile strength and elastic modulus of aisi1080 steel, it is more appropriate that the container should be placed 38m below sea level, and its specific depth can fluctuate up and down, and the fluctuation value shall not exceed two meters.

Tides and seasons will change local water level and temperature, and bring temporary sea water flow. Because tides are affected by geographical location, the time and type of tides are different in different areas. Therefore, we select Dachan island area of neilingdingyang as the research object for analysis. During spring tide, the water flow speed is obviously accelerated, and the heat dissipation balance of containers is accelerated. But at the same time, the container force also increases, so we need to grasp the number of servers in the container. Generally, it is not affected by the tide when it is about 50 meters under the sea. However, the maximum depth that the existing materials can reach is less than 50 meters under the sea. Therefore, the influence of the change of tide on the heat dissipation efficiency of containers can not be ignored. In addition, under a certain depth of sea water, with the seasonal change, the sea water temperature does not change greatly, so the influence of season on the container heat dissipation effect of undersea data center can be ignored.

3. Model Evaluation and Application

Firstly, we use a simple geometric analysis method to select the structure. The model is easy to understand. After determining the general structure, we add fins to make the heat dissipation more sufficient. In the selection of container shell materials, we establish the main factor analysis model to sort the influencing factors reasonably, the process is rigorous and the result is accurate. In solving the problem of this paper, we make the following assumptions. It is assumed that each IU server runs stably and produces 500 W of heat; It is assumed that the heat conduction per unit time in the convective heat transfer process of solid and liquid is fixed; It is assumed that the heat is transferred along the normal direction of the container shell, and the surface of the container shell is heated evenly; It is assumed that the data of material parameters are accurate; It is assumed that the velocity of sea water is constant. However, in the process of solving, some limiting conditions are assumed not to exist or have no influence, which leads to the difference between the results of this paper and the reality. We introduce the error constant as much as possible to offset the error in the solution process.

All the analyses in this paper are based on one-dimensional heat conduction model, so the conclusions of the fin analysis need to be treated carefully. In order to get a more accurate analytical solution, it is necessary to use two-dimensional or even three-dimensional thermal conductivity model, and also consider the variation of thermal conductivity with temperature and the real difference of external heat transfer coefficient in different parts of the fin.

This model can not only be applied to the heat dissipation of undersea data center, but also play a corresponding role in CPU heat dissipation, aerospace engineering heat dissipation, large-scale industrial equipment and electrical equipment. But in different application fields, the requirements of heat dissipation are not the same, so the heat dissipation model needs to be further optimized and improved according to the actual situation.

4. Conclusion

Internet big data is a trend of future development. Data center in coastal cities is growing rapidly, and the construction cost on land is higher, occupying more land, consuming a lot of power and cold water resources when cooling, which leads to the prominent resource contradiction. The undersea data center is to serve each other with offshore wind power, offshore oil and other industries. It is deployed in coastal urban waters to shorten the distance between data and users, and the Internet facilities such as servers are installed in the undersea closed pressure vessel with advanced cooling function. The undersea composite cable is used for power supply and heat exchange with a large amount of flowing seawater to heat the Internet facilities, and the data is sent back to the Internet, which skillfully solves a series of problems arising from the construction of the data center in the inland. At present, undersea data center is an emerging industry, and there are still many aspects to be optimized. We have carried out the following optimization:

First of all, compared with other cubes, the cylinder has the smallest surface area and the smallest pressure when the sea water depth is the same. Therefore, we suggest that the large structure of container shell is cylinder. Compared with other fins, flat fins increase the largest surface area, and flat fins can be divided into several types. Different container materials have different heat transfer coefficients, and the optimal flat fin type is also different. According to the range of heat transfer coefficients of different materials, the corresponding flat fin type is selected.

Secondly, there are many known types of materials and their properties are not the same. When selecting the container structure materials, we should make a preliminary selection on the basis of whether they can contact water, material cost, water absorption, seawater corrosion resistance, heat dissipation coefficient and so on. In addition, refer to the tensile strength and yield strength of the materials used to measure which materials should be selected. If the material evaluated in this way is vulnerable to corrosion, we can prevent corrosion by painting. Here we suggest to use AISI 1080 steel, 302 stainless steel, HY-100 steel, AISI 1040 steel and other materials, which are more economical and durable.

Then, we take Dachan island of Lingdingyang as the research object to analyze, establish two-dimensional flow equation, and get the influence of tide on the temperature field and velocity field. At the same time, we analyze the influence of seasonal change on water temperature in Dachan island of Lingdingyang in the south. To sum up, the seasonal change has little effect on the heat dissipation efficiency of containers, and the tide will have a greater impact on the heat dissipation efficiency of containers. We should take some measures to weaken this effect.

Finally, we conducted a comprehensive evaluation of the model, analyzed its advantages and disadvantages, as well as the limitations and errors in the processing and calculation methods of this article. At the same time, we think about the improvement and development of this model, and explore the application of one-dimensional heat conduction model of thin-walled fin in other fields.

With the prevalence of big data era and the continuous improvement and development of scientific level, in the future, we may explore more methods and ways to cool the undersea data center, and find more reliable materials and technologies. Undersea data center will become a new trend in the future, and play an important role in the global cloud computing platform on the basis of saving more resources and energy consumption.

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