Calculation of Plain Rectangular Duct Radiators Used in Near Spacecraft

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Abstract

In spacecraft thermal control systems, plain rectangular duct radiators are widely used heat sinks. Plain rectangular duct radiators are a flat tube, the left and right surface or unilateral surface as the radiation heat surface. In this paper, plain rectangular duct radiators are applied to the near spacecraft, and a detailed thermal analysis of the double-sided plain rectangular duct radiators is made. Convection heat transfer and radiative heat transfer are considered. Finally, the relationship between the temperature of the fluid and the length of the radiator is deduced to complete the performance calculation of the radiator.

Keywords

Radiation heat transfer, heat sink, thermal analysis.

1. Introduction

Plain rectangular duct radiators are the heat transfer device used by the spacecraft to achieve radiation between spacecraft and space environment. It is an important part of the spacecraft heat rejection system. Radiator heat rejection system coupling between the heat source and the radiator can be divided into two categories: (1)Direct Coupling - the heat source and the radiator links in the form of radiation or conduction. This type of coupling is mostly used for low-power heat rejection systems. (2) Convection Coupling - connects heat sources to radiators through fluid circulation. It is used more in more high-power heat rejection system. The specific structure of convection-coupled radiators is varied, while the typical and commonly used convection-coupled radiators are plain rectangular duct radiators.

Structures of plain rectangular duct radiators actually consist of a flat rectangular duct. Its main radiant heat surface is one side of the catheter or both sides, coated with a low absorption rate, high emissivity organic thermal control coating. When the working fluid flows through the tube, the heat is transferred to the tube surface and the heat is radiated by heat transfer.

Because of its external environment is the bottom of the stratosphere, although the atmosphere is relatively thin, but the ambient temperature is low, and has a certain wind field, so the plain rectangular duct radiators applied to nearby space are different from plain rectangular duct radiators used in outer space. There are also convection heat transfer surface at the heat exchanger. Based on this situation, in this paper, the design and calculation of plain rectangular duct radiators not only have the conventional radiation heat transfer, but also consider the convection heat transfer, and deduce the corresponding formula.

2. Thermal Analysis and Calculation of Plain rectangular duct radiators

The main design idea of plain rectangular duct radiators is to derive the differential equation of the catheter surface temperature and the working fluid flows temperature on the basis of the detailed thermal analysis. The above differential equation is solved along the surface of the catheter under the condition of determining certain structural parameters (width and thickness of the catheter) and the temperature of the inlet and outlet of the working fluid flows. Finally, the length parameter of the catheter is obtained.

When the working fluid flows through the conduit (length is L_w), the temperature of the refrigerant drops from T_{f1} down to T_{f1}, correspondingly, the wall temperature of the conduit drops from T_{w1} down to T_{w2}.(Due to the thin wall of the conduit, the high thermal conductivity of the metal material can be neglected, so we can see that both the inner and outer wall mild temperature are the same).

Take a micro-pipe length in the pipe length, the net heat exchange when the wall temperature is T_w:

$$dQ_r = \left(C_\varepsilon T_w^4 - q_a\right) L_d * dL + h_{fd} (T_w - T_\infty) L_d * dL \quad (1)$$

Where:

$$C_\varepsilon = 2\sigma\varepsilon \quad (2)$$

$$q_a = Q_s + Q_r + Q_{ea} \quad (3)$$

In this paper, we consider the two-sided radiation, so $C_\varepsilon = 2\sigma\varepsilon$, if only consider unilateral radiation, $C_\varepsilon = \sigma\varepsilon$.

h_{fd} is the convective heat transfer coefficient between the left and right sides of the plain rectangular duct radiators and the air. Since the air fluid is the side of the external swept duct, we adopt the following correlation formula of h_f for the mean flow heat transfer coefficient:

$$N_u = \frac{h_{fs} * L_w}{\lambda} = 0.664 * \mathrm{Re}^{\frac{1}{2}} * \mathrm{Pr}^{\frac{1}{3}} \quad (4)$$

$$\mathrm{Re} = \frac{V * L_w}{\nu} \quad (5)$$

$$\mathrm{Pr} = \frac{\nu}{a}, a = \frac{\lambda}{\rho C_p} \quad (6)$$

By the above three types, h_{fd} can be obtained, because the air is swept flattened catheter outer space radiator around the two surfaces, so:

$$h_{fd} = 2 * h_{fs} \quad (7)$$

When the refrigerant passes through the same micrometer section, the amount of heat released is:

$$dQ_f = -\dot{m}_f C_p dT_f \quad (8)$$

The working fluid flows are released by heat convection heat transfer to the pipe wall:

$$dQ_f = h_f \left(T_f - T_w\right) pdL \quad (9)$$

In the formula, the subscripts f represent refrigerant body; $\dot{m}$ represent the mass flow rate; P represent the pipe cross-section perimeter; h_f represent the refrigerant and the pipe wall heat transfer coefficient; C_p represent the ratio of refrigerant heat.

From the heat balance we can see $dQ_r = dQ_f$, so:

$$\left(C_\varepsilon T_w^4 - q_a\right) L_d + h_{fd} \left(T_w - T_\infty\right) L_d = Ph_f \left(T_f - T_w\right) \quad (10)$$

The above expressions show the relationship between the coolant temperature and the tube wall temperature one by one.

In the above equations, the convective heat transfer coefficient between the refrigerant and the wall of the tube is the experimental correlation proposed by Seidel Tatel in the tube:

$$N_{uf} = 1.86 \left(\mathrm{Re} * \mathrm{Pr} * \frac{D_h}{L_w} \right)^{\frac{1}{3}} \left(\frac{\mu_f}{\mu_w} \right)^{0.14} \quad (11)$$

Using equation (10), we can get T_{w1} and T_{w2} by computer iteration.

From equation (1) and equation (8) can be obtained:

$$\left\{\left(C_{\varepsilon}T_w^4-q_a\right)+h_{fd}\left(T_w-T_{\infty}\right)\right\}L_d dL=-\dot{m}_f C_p dT_f \quad (12)$$

Differential equation (10):

$$dT_f=\left(\frac{4C_{\varepsilon}L_dT_w^3+h_{fd}L_d+Ph_f}{Ph_f}\right)dT_w \quad (13)$$

Into equation (12):

$$\left\{\left(C_{\varepsilon}T_w^4-q_a\right)L_d+h_{fd}\left(T_w-T_{\infty}\right)\right\}L_d dL=-\dot{m}_f C_p\left(\frac{4C_{\varepsilon}L_dT_w^3+h_{fd}L_d+Ph_f}{Ph_f}\right)dT_w \quad (14)$$

The above equation is the differential equation between tube wall temperature T_w and tube length L.

3. Conclusion

By the above formula, when determining the flat pipe structure conditions and the import and export of working fluid flows under the same conditions, we can have plain rectangular duct radiators related performance calculations.

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