Integrated Application Method for KOBEHONETSU™ Steel Sheet

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KOBEHONETSU is the trade name for a steel sheet having heat-radiation ability. A method was developed for applying this steel sheet to dissipate heat in high-performance electronic equipment. By applying KOBEHONETSU to both the heat sink and housing simultaneously, the amount of heat transferred out of an electronic device was significantly increased to a level comparable with that achieved by a cooling fan. This cooling effect is enhanced by increasing the heat sink area, which makes KOBEHONETSU more applicable to heat sources such as CPUs. For example, this steel sheet can be machined into heat sinks, while maintaining its area and heat dissipation capability, for cases where heat sinks may interfere with other parts.

Introduction

An increasing number of home electronic and office automation products have become digitally operated. In the digital circuits of these products, most semiconductor devices work as on/off switches. The on/off action of these semiconductor devices consumes electrical energy, but the greater part of the energy supplied escapes as heat. Higher-speed semiconductor devices consume more power, increasing the amount of heat generated and raising the temperature. In other words, improving the performance of a digital instrument is inevitably associated with an increased amount of heat being generated and a rise in temperature.

A rise in the internal temperature of an instrument can cause its semiconductor devices to malfunction, cause the characteristics of its elements, such as resistors, to change, and shorten the overall life of electronic components containing organic insulation. To resolve these issues, heat dissipation technologies have been developed for efficiently inducing the heat generated inside an instrument to move away from the heat source and exit the instrument. The heat dissipation employs various techniques such as heat sinks and fans.

As a manufacturer of steel sheets for the covers and chassis of home electronic appliances and office automation equipment, Kobe Steel supplies KOBEHONETSU, a steel sheet having heat radiation ability[1]. KOBEHONETSU is widely used as steel sheet with increased thermal emission from its surface. When used for the cover of a home electronic appliance or of an office automation apparatus, for example, it efficiently dissipates the internal heat to the outside by radiation heat transfer and lowers the internal temperature of the instrument.

The efficiency of radiation heat transfer is proportional to the fourth power of the absolute temperature. Therefore, the higher the internal temperature of an instrument, the higher the heat radiation efficiency. On the other hand, heat radiation works less efficiently when the ambient temperature is low and the difference between the ambient and internal temperatures is small.

This paper introduces a method of achieving a heat radiation effect comparable to that of a cooling fan, even when the ambient temperature is low and the difference between the ambient and internal temperatures is small.

1. Principle of heat radiation structure

The amount of heat transferred by thermal radiation is considered using a semi-cylinder model consisting of a gray body having a heating element, an enclosure and an outer space, which are located in that order from inside out (**Fig. 1**)[1]. In the figure, the symbols ①, ②, ③ and ④ represent the heat radiation surface of the heating element, the inner surface of the enclosure, the outer surface of the enclosure and the surface facing the outer space, respectively. Their surface areas are represented by A_1, A_2, A_3 and A_4, while their emissivities are represented by ε_1, ε_2, ε_3 and ε_4, respectively. The surface temperature of the heating element is denoted by T_1, the inner surface temperature of the enclosure by T_2, the outer surface temperature of the

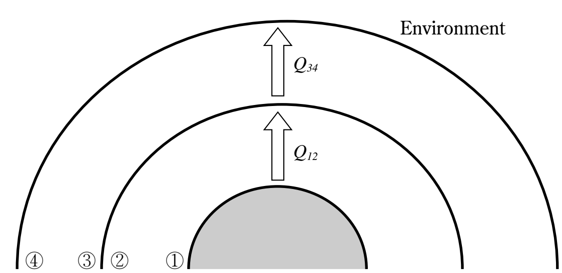

Fig. 1 Calculation model for thermal radiation transfer

enclosure by T_3, and the temperature at the wall surface facing the outer space by T_4. Ignoring the heat transfer by thermal conduction and convection, the radiation amount Q_{12} (W) from the heating element to the enclosure is given by equation (1).

$$Q_{12}=\frac{A_1\sigma\,(T_1^{\,4}-T_2^{\,4})}{\dfrac{1}{\varepsilon_1}+\dfrac{A_1}{A_2}\left(\dfrac{1}{\varepsilon_2}-1\right)} \quad \cdots\cdots(1)$$

On the other hand, the amount of radiation Q_{34} (W) from the enclosure to the outer space is given by

$$Q_{34}=\frac{A_3\sigma\,(T_3^{\,4}-T_4^{\,4})}{\dfrac{1}{\varepsilon_3}+\dfrac{A_3}{A_4}\left(\dfrac{1}{\varepsilon_4}-1\right)} \quad \cdots\cdots(2)$$

where σ is the Stefan-Boltzmann constant having a value of 5.667×10^{-8}(W/m^2K^4). Assuming that T_2 is equal to T_3 in equation (1) and equation (2), T_1 is given as follows:

$$T_1=\left[T_4^{\,4}+\frac{Q_{12}}{A_1\sigma}\left\{\frac{1}{\varepsilon_1}+\frac{A_1}{A_2}\left(\frac{1}{\varepsilon_2}-1\right)\right\}+\frac{Q_{34}}{A_3\sigma}\left\{\frac{1}{\varepsilon_3}+\frac{A_3}{A_4}\left(\frac{1}{\varepsilon_4}-1\right)\right\}\right]^{\frac{1}{4}} \quad \cdots\cdots(3)$$

equation (3) was used to study the effect on heating element temperature caused by the surface area of the heating element and the emissivity of the enclosure (**Table 1**). Here the following assumptions were made, i.e., the amount of heat generated is 0.3W and the wall surface facing the outer space has an area of $100m^2$, an emissivity of 0.99 and a temperature of 25℃. Case 1 assumes that the enclosure is made of an electrogalvanized steel sheet. The heating element temperature for this case is calculated to be 79℃. Case 2 assumes that the enclosure is made of KOBEHONETSU. The heating element temperature for this case is calculated to be 74℃. Case 3 assumes that the heating element has an emissivity equal to that of KOBEHONETSU and has twice as much surface area. This case also assumes that the enclosure is made of KOBEHONETSU. In Case 3, the temperature of the heating element is lowered to 53℃. Case 4 assumes that the heating element has a surface area three times larger. The heating element temperature for this case is lowered to 44℃.

These results indicate that the temperature can be lowered significantly by increasing the emissivity, as well as the surface area, of the heating element and by increasing the emissivity of the enclosure. The following introduces the demonstration of these analysis results.

Table 1 Influences of surface area and emissivity of heating element and emissivity of housing on temperature of heating element

Case	A_1 (cm^2)	$A_2=A_3$ (cm^2)	ε_1	$\varepsilon_2=\varepsilon_3$	$Q_{12}=Q_{34}$ (W)	T_1 (℃)
1	10	1,200	0.8	0.1	0.3	79
2	10		0.8	0.86		74
3	20		0.86	0.86		53
4	30		0.86	0.86		44

2. Experimental verification of heat radiation structure

An apparatus, shown in **Fig. 2**, was made for experimentally verifying the calculation results obtained in the previous section. The enclosure, having an opening at the front, was made of an electrogalvanized steel sheet and had a dimension of 300mm(W)×88mm(D)×250mm(H). Vent holes, each sized 100mm×30mm, were provided at the top and bottom to allow cooling by natural convection, the cooling method commonly employed by actual instruments. A ceramic heater (1.8W), sized 25×25×2mm, mounted on an electronic board, was provided on the surface at the far end of the enclosure. This apparatus was used to compare the temperatures of the ceramic heater in the following four cases:

1) The opening at the front was closed with an electrogalvanized steel sheet (**Fig. 3** (a))
2) The opening at the front was closed with a KOBEHONETSU sheet (Fig. 3 (b))
3) The opening at the front was closed with an electrogalvanized steel sheet with a fan provided at the center of the sheet so as to cool the ceramic heater directly (Fig. 3 (c)) and

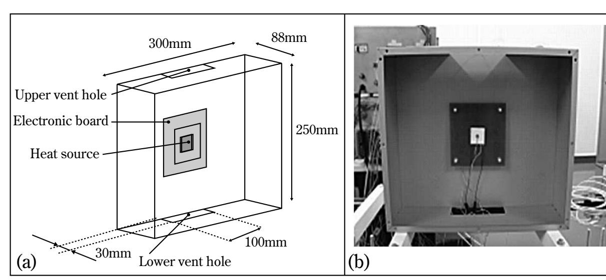

Fig. 2 Experimental apparatus for heat radiation structure

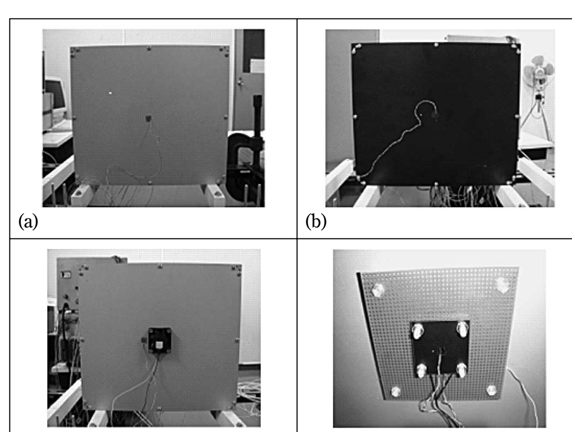

Fig. 3 Cooling method of heat source

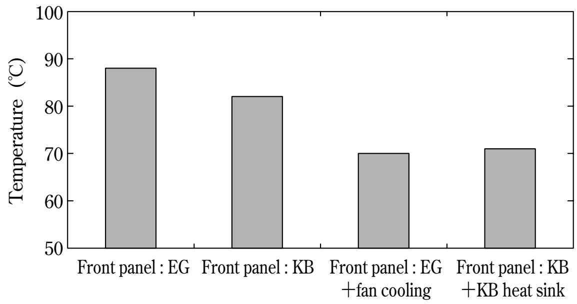

Fig. 4 Effects of heat radiation structure
(EG : Electrogalvanized steel sheet, KB : kobehonetsu)

4) The opening at the front was closed with a KOBEHONETSU sheet, while the ceramic heater was covered by a heat sink (40×40mm) made of KOBEHONETSU (Fig. 3 (d))

As shown in **Fig. 4**, the results indicate that the ceramic heater covered with a KOBEHONETSU sheet exhibited a heat dissipation comparable to that of the cooling fan.

3. Method for effectively utilizing heat radiation structure

As reported in the previous section, a ceramic heater, sized 25×25mm, covered by a piece of KOBEHONETSU, 40×40mm, realizes a temperature reduction of 17℃. The results shown in Table 1 also suggest that increasing the size of the KOBEHONETSU sheet placed on the heater should lower the temperature even further. To verify this and to establish a guideline for the size of a KOBEHONETSU heat sink that will achieve the desired temperature, an analysis was conducted according to the simulation model shown in **Fig. 5**. The results are shown in **Fig. 6**. The heat source temperature decreases with the increasing area of a KOBEHONETSU heat sink. This suggests that the heat sink area can be set up according to the target temperature.

There may be cases where the heat sink area cannot be set up in a desired size, due to other components located near the heat source (**Fig. 7**). In such cases, the heat sink can be adapted to avoid interference with neighboring components. Several examples are shown in **Fig. 8**, and the results of the corresponding temperature calculations are shown in **Table 2**. The heat source temperature can be decreased by increasing the heat sink area, while avoiding interference with neighboring components, as shown by Case (c) and Case (d). Even in a case where a vertical surface exists in the heat source, as in Case (d), a KOBEHONETSU heat sink is effective in lowering the temperature.

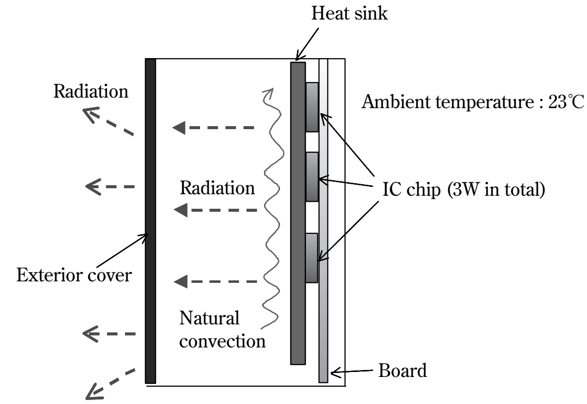

Fig. 5 Simulation model for heat radiation structure

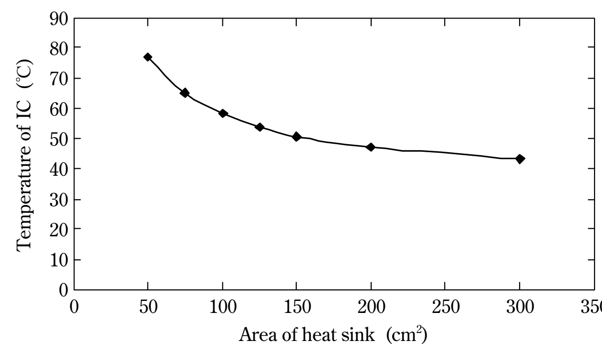

Fig. 6 Effects of heat sink area on heat source temperature

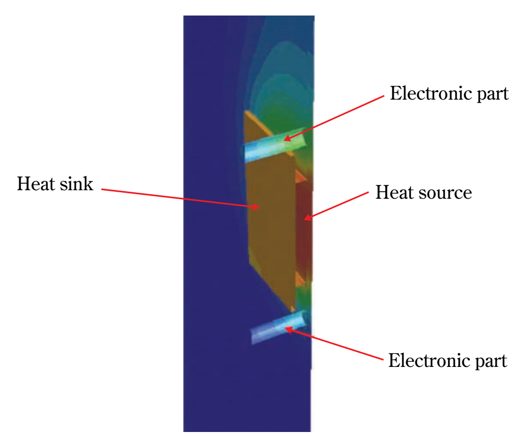

Fig. 7 Constraints on heat sink due to other electronic components

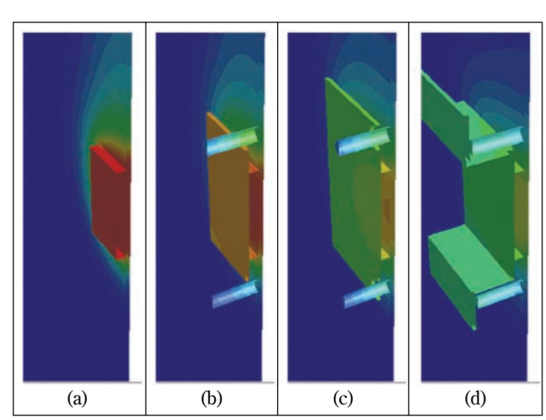

Fig. 8 Cases of setting up heat sink in case of parts close to heat source

Table 2 Temperature reduction by setting up heat sink in case of parts close to heat source

Case	Area of heat sink (cm^2)	Temperature of heat source (℃)
(a)	None	103
(b)	9	79
(c)	16	68
(d)	20	62

Conclusions

The interior temperatures of electronic instruments have come close to the heat resistance limit of arithmetic elements such as CPUs. The life of the precision components is in question. KOBEHONETSU offers a method for lowering the internal temperature of electronic instruments without decreasing the air-tightness of the apparatus. KOBEHONETSU can be used not only for covers, but also for heat sinks, the combination of which decreases the temperature of the heating elements even further, allowing the use of cooling fans with smaller capacities, or even their elimination, which leads to cost reduction. KOBEHONETSU is expected to further contribute to the improvement of instrumental performance, in terms of performance upgrading, downsizing, energy saving and noise reduction.

References

1) Y. HIRANO et al., *R&D KOBE STEEL ENGINEERING REPORTS*, Vol.54, No.1 (2004), p.58.