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Performance Curve of a Patch Heater Fabricated by Silver Screen Printing for Satellite Applications

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Abstract **-** This study handled a heater fabricated by silver screen printing for satellite applications. In the space environment, heat is transferred only by conduction and radiation. The designed heater for typical use is 152.4mm in width and 25.4mm in length, and the thickness does not exceed 2mm. It was manufactured according to the ESCC (European space components coordination) standard. When the experiment is conducted at room temperature, convection occurs on the surface, and thermal contact resistance occurs when the heater and CFRP (carbon fiber reinforced plastic) are bonded. A temperature measurement experiment was conducted for the heater, and the convective heat transfer coefficient and thermal contact resistance were found by comparing with the simulation value. Based on this simulation method, vacuum analysis is performed by applying a heater attached to CFRP. A performance curve of the heater was prepared, which enables the calculation of the power according to the operating environment temperature of the heater.

***Keywords*:** Patch heater, Silver paste, Thermal contact resistance, Power density

1. Introduction

Satellites in orbit encounters a space environment with extreme temperature differences. If electronic devices inside satellite are not maintained at an appropriate temperature, fatal problems may occur in the system. To solve this problem, there are many thermal control devices for total thermal energy management in satellites, where heat conduction and radiation dominate. Patch heaters that provide just the right amount of heat need to be properly attached around the device and actively control a localized heat transfer to protect the satellite's electronics.

Only limited materials have been validated for heaters in space applications. Common examples include Inconel, Kapton film, adhesives, terminals and wires. Patch heaters are manufactured through several processes. This study applied silver paste as a heating element [1]. It is also produced using a screen-printing technology. This method is much faster and more economically efficient than the conventional method. Safety and reliability have also been confirmed. A point of the heater study is how to attach it to the structure. Adhesive (3M-966) is mainly used to attach patch heaters to base materials in space environments [2]. This adhesive is suitable for use in the space environment through performance tests such as outgassing. However, the physical properties of 3M-966 may change when the temperature exceeds 150℃. For example, excessive energy is generated in the heater due to problems such as adhesion condition. This can cause to failing temperature control and electronic equipment [3]. It is necessary to calculate and use the appropriate power.

In this study, performance curve of a patch heater fabricated by silver screen printing for satellite applications was investigated. A patch heater for testing was fabricated by a screen-printing process using silver paste. First, thermal processes are predicted through experiments and numerical calculations in single mode with only a heater. Since patch heaters are exposed to atmospheric conditions, convective heat transfer occurs on the surface. An appropriate convective heat transfer coefficient is obtained by comparing experimental data and numerical values. Experimental and numerical calculations are conducted in attached mode where the patch heater is attached to the CFRP (carbon fiber reinforced plastic) plate. Through this, the value of the thermal contact resistance due to the adhesive can be inferred. Finally, among the boundary conditions, the convection condition is replaced with the radiation condition. This is to verify the performance of the patch heater in the still-air condition in a vacuum. In this process, it is to predict the power per unit area to reach the target temperature and organize it by the surrounding sink temperature.

2. Analysis method

2.1. Heater design and manufacturing standards

The pattern and structure of the heating element are shown in Fig. 1. To efficiently generate heat in a limited area, the distance between the heating wires was designed to be close. As the device width decreases, the overall length increases and the cross-sectional area decreases. If a high voltage is applied to a low-resistance model in a space environment, the output is high, and durability may be reduced. In this study, a pattern width of 1 mm that can maintain high resistance was used. For an even distribution of heat, the pattern is symmetrical. According to the ESCC (European space components coordination) standard, the ratio of the element area in the heater area is $50\% \pm 10\%$ [4]. The value of this heater is 49.4%. It is suitable for satellite applications. There are also standards for thickness. The maximum thickness of a heater with a one-layer heating element structure is 0.2mm. The heater used in this study was also made with a thickness of 0.2 mm. In the case of the attachment mode, it was attached to the CFRP using 3M-966 adhesive. CFRP is 250mm wide and 2mm thick.

2.2. Thermal measurements and simulations

Fig. 2 shows the experiment for single mode and attached mode. In the case of single mode, only the heater exists, so the terminal part of the heater is fixed with a clamp and hung. A FLIR (Forward Looking infrared) camera was placed in front of the heater to take pictures from the front. The resistance of the heater was measured as 545Ω. The experiment time was 300 seconds, and the applied voltage was 28V. In attachment mode, CFRP was placed horizontally with the floor. This is because placing them vertically can affect the direction of the heat. The camera was placed to look down from above. A higher voltage was applied to polarize the heat.

Computational model and boundary conditions were created to calculate the same conditions as the experiment. Since convection occurs on the surface, the convective heat transfer coefficient must be obtained. In the case of CV 1, convection occurs on both sides of the heater, and CV 2, it occurs on the top of the heater and the bottom of the CFRP. To simplify the calculations, there are two variants. First, all sides are adiabatic because the model is too thin. Second, the adhesive has been replaced by thermal contact resistance. This value is only meaningful for CV 2. It is detailed in the 3rd figure of Fig 2.

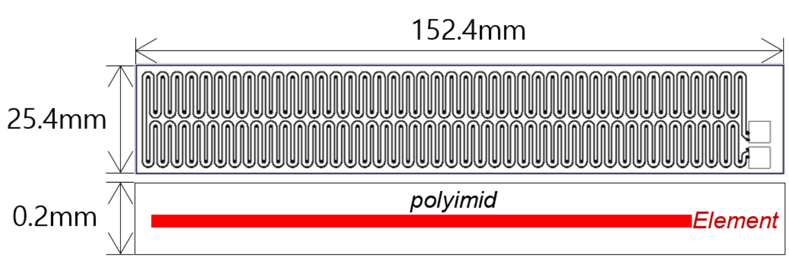

Fig. 1: Pattern and design of patch heater

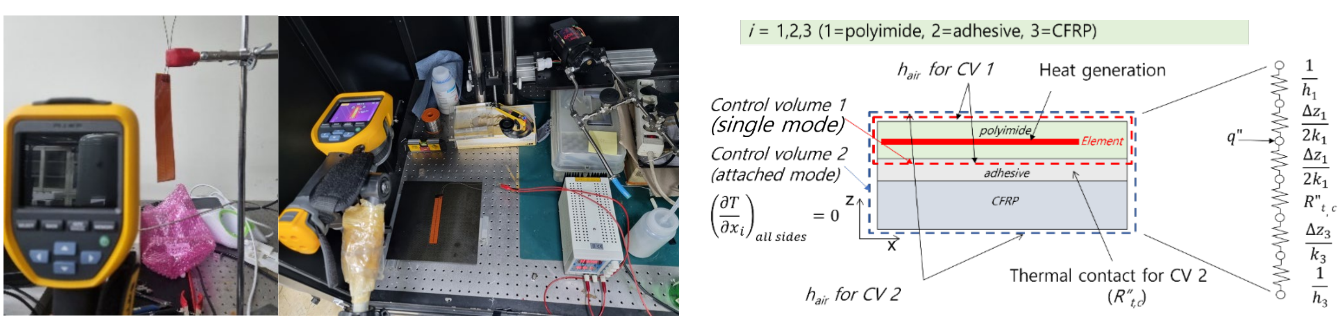

Fig. 2: Experiment of single, attached mode and patch heater model, boundary conditions for analysis

3. Results and discussion

3.1. Power density and temperature variations

Fig. 3 is a temperature graph of the experimental and analysis values of the single and attached mode heater used in this study. In single mode, the experiment was carried out at room temperature, and the result showed a steady state progressed up to 300seconds. The polyimide film receives constant heat from the heating wire, and the temperature reaches a certain level and converges. The higher the power, the larger the critical temperature of the heater and the shorter the time it takes to reach it. However, if the power is too high, temperatures exceeding the material's heat resistance requirements can be reached. The natural convective heat transfer coefficient for the analysis was set to 8W/m^2K. The temperature of the heater converges due to natural convection through the air. There is a slight error due to the simplification of modelling and the difference in the actual convective heat transfer coefficient, but the trend of temperature increase is very similar.

After being attached, heat is transferred by conduction to the CFRP plate. So, it is necessary to check how much the heat spreads and rises when the patch heater is attached to the base material. After giving enough time for thermal diffusion, experiments and analysis were performed for 1800seconds, and the power was turned off for 1800 seconds to measure the temperature drop. In the analysis Fig. 2, the adhesive was set as the thermal contact resistance. The thermal contact resistance was set to 0.01 m^2K/W. Also, since it is not a vacuum test, heat transfer by convection occurs on the surface. Considering the laboratory environment, the convective heat transfer coefficient was set to 8W/m^2K. The average temperature of polyimide was about 110℃, and the CFRP surface temperature at a point 1 cm away from the heater was measured about at 60℃. The contact heat resistance and convective heat transfer coefficient were adjusted, and the value when the experimental value and the analysis value were closest were used. The efficiency in heat transfer is lower because it is not 100% contact between adhesive and CFRP.

3.2 Performance curve of the patch heater in space environment

Power density represents the value of power per area as a variable when comparing heater performance where P is power, A is actual area which is not contain terminal and margin area, I is electric current, V is voltage and R is resistance.

$$Power\ Density = \frac{P}{A} = \frac{IV}{A} = \frac{V^2}{RA}\ [W/cm^2] \tag{1}$$

In the boundary conditions of the attached mode, the convection condition was removed, and the radiation condition was substituted. This is a calculation assuming a space environment. Since the temperature of the space environment progressed from -150 to 100℃ at 50℃ intervals. The (a) curve of Fig. 4 shows the maximum temperature graph for each sink temperature. For the same power density, the lower the sink temperature, the lower the maximum temperature. Because adhesive cannot withstand more than 150℃, it is taken as a reference point. The power density of the intersection points was extracted and shown in the (b) curve of Fig. 4. This graph becomes the performance curve of the heater. The power density to reach 150℃ is arranged. Characteristically, as the sink temperature increases, the power decreases. Overall, it takes the form of a curve, and the reduction rate increases at higher sink temperatures. This can be a reference

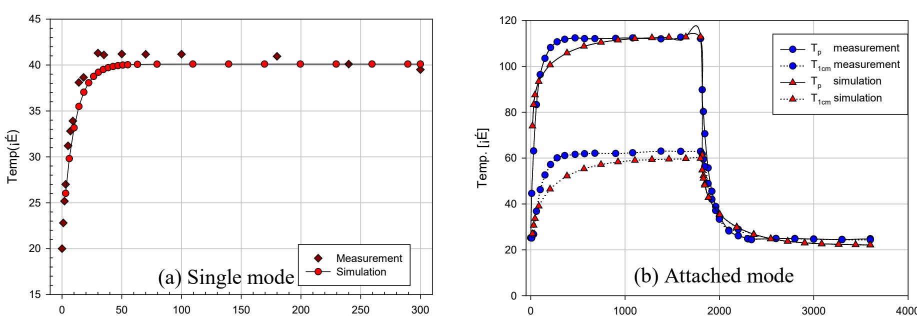

Fig. 3: Comparison graph of measurement and calculation temperature data of single(a) and attached(b) modes

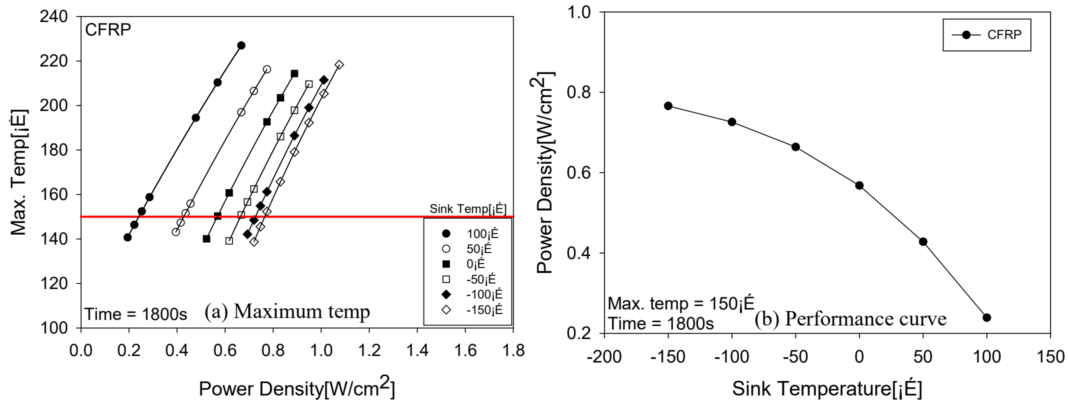

Fig. 4: Maximum temperature(a) and performance curve(b) of radiation condition calculation of attached mode

when mounting the heaters on the satellite. It is easy to control the voltage as the power can be calculated according to the operating temperature. It can also improve durability by preventing the heater from overloading.

4. Conclusions

In this study, performance curve of a patch heater fabricated by silver screen printing for satellite applications was investigated. The experimental and simulated values for single mode and attached modes are very similar. Through this, the result was obtained. First, the thermal contact resistance between polyimide, adhesive, and CFRP was calculated as $0.01 m^2$K/W. Second, the performance curve of the attached mode in space environment was completed through the calculated thermal contact resistance. As the sink temperature increases, the power density decreases. The shape of the line is not straight but curved. Therefore, reduction rate increases at higher sink temperatures.

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References

[1] J. H. Kim, J. Choi, J. Sung, G. Lee, M. Kim and Y. J. Cho, "Thermal Analysis of Film Heaters with a Silver-Paste Heating Element Fabricated using Screen Printing Process for Satellite Applications," in *Journal of the Korean Society of Manufacturing Technology Engineers*, 2021, vol. 30, no. 6, pp. 495-504.

[2] S. Kang, D. Lee, S. Shin, D. Choi, and M. Jeong, "An Experimental Study for Effect of Bonding Process on Heating Performance of Patch Heater Using in Satellite," *The Korean Society for Aeronautical & Space Sciences 2018 Fall Conference*, 2018, pp. 178-179.

[3] C. H. Lee, J. J. Lee, Y. K. Kim, "Failure Mode Analysis and Process Verification of Patch Heater used in Satellite," *The Korean Society for Aeronautical & Space Sciences 2017 Fall Conference*, 2017, pp. 980-983.

[4] European Space Agency, "Resistors, Heaters, Flexible Single and Double Layer," in *ESCC Detail Specification*, 2020, vol. 9, no. 2, pp. 1-16.