

Study on Evaluation of Local Cooling Performance using Piezoelectric and Thermoelectric Modules

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압전소자와 열전소자를 이용한 국소부 냉각성능 평가에 관한 연구

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Abstract This paper investigated experimentally the performance of cooling systems using thermoelectric and piezoelectric modules for local heating and temperature control, such as a handheld electronic devices. The temperature distribution of the cooling region using thermoelectric modules was measured when the piezoelectric module was and was not with a frequency of 80Hz and 110Hz. The coefficients of performance were also calculated by the temperature results, and the thermo-flow phenomena in the cold region was visualized under the same conditions. The results of the temperature distribution measurements and the coefficient of performance showed that the cooling performance of the cooling system using thermoelectric modules can be improved by operating the piezoelectric module. In addition, when the piezoelectric module was operated based on the result of visualization in the cold region, which was formed by thermoelectric modules, the performance thermoelectric cooling was improved by the thermo-flow formed in the entire cold region as the forced convection of vibration was generated on the local cold region by the piezoelectric module.

요약 본 논문에서는 소형 전자기기와 같은 발열부 온도 제어를 위해 압전 소자와 열전 소자를 이용하여 국소부 냉각 성능을 실험적으로 조사해 보았다. 실험은 열전 소자를 이용하여 실험 영역내에 냉각부를 형성하고, 압전 소자에 80Hz와 110Hz의 인가주파수를 각각 적용하여, 압전 소자를 작동시켰을 때와 작동시키지 않았을 때 열전 소자에 의해 형성된 시험부의 냉각 영역에서 온도 분포를 측정하였다. 또한, 냉각 영역의 온도측정 결과를 토대로 압전 소자를 적용하였을 때와 적용하지 않았을 때 냉각 영역의 성능 계수를 계산하고, 가시화 장치를 구성한 후 시험부내에 냉각 영역의 열유동 현상도 확인해 보았다. 실험결과, 온도분포 측정 실험 결과와 성능 계수 계산 결과로 부터 압전 소자를 작동하지 않은 경우보다 압전 소자를 작동한 경우에서 냉각 성능이 개선되는 것을 확인할 수 있었다. 또한, 가시화 결과를 토대로 열전 소자에 의해 형성된 냉각 영역에 압전 소자를 작동시켰을 경우에 냉각 영역의 국소부에 압전 소자에 의한 상하 진동의 강제 대류 현상이 발생하면서 냉각영역 전체에 고르게 분포하는 유동을 형성하고 냉각 성능이 개선되는 원인을 확인할 수 있었다.

Keywords : Cooling Performance, Forced Convection, Piezoelectric Module, Thermo-Flow, Thermoelectric Module

1. Introduction

Generally, the cooling system is applied the vapor compression refrigerating method using refrigerant

gases by compressor. But, refrigerant gases are occurred serious environmental pollution when the gases are emitted into the atmosphere. So, most countries have been trying to restrict the use of

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refrigerant gases and many researchers have been studying alternative methods on development of eco-friendly refrigerants and new cooling system[1].

In recently, the cooling system using thermoelectric module is one of new eco-friendly cooling method and have been researching and applying with various methods. The cooling system consisted with compressor, condenser and evaporator using refrigerant has large size, noise, vibration, environmental problem and problems of energy efficiency. However, thermoelectric module has small size and light in weight and don't occurred noise and vibration. Due to above merits, thermoelectric module has been widely used and applied in the field of aerospace, military, medicine, semiconductor and etc[2]. But, the cooling system using thermoelectric module has demerits of the low cooling performance compared to pre-existing cooling system. So, many studies have been performed with various methods for improving the performance of the cooling system using thermoelectric module[3].

In this study, piezoelectric module is addedly used for improving the performance of the cooling system using thermoelectric module. The actuator using piezoelectric module generates the vibration by piezoelectric reverse effect and it has high resolvability, driving power and response of frequency[4,5]. So, piezoelectric module is widely used for controlling shape and posture of structures, automatic control, piezoelectric diagnosis and etc[6]. This study is experimentally measured the temperature distributions and visually verified the thermo-flow phenomena in the cold region of cooling system using thermoelectric module with and without piezoelectric module. Also, the coefficient of performance was calculated from the results of temperature measurement to confirm the improvement of cooling performance.

2. Experiments

In order to verify on the improving performance of

cooling system, the experiment was performed the measurement of the temperature distribution in the cold region using the thermoelectric module when the piezoelectric module wasn't and was operated with the changing frequency. Also, the visualization experiments on thermo-flow phenomena in the cold region was performed to find the cause on improvement of cooling performance.

2.1 Experiment for temperature measurement

As shown in Fig. 1, the experimental set-up for temperature measurement consists of the cooling system using thermoelectric and piezoelectric modules, T-type thermocouples, data acquisition unit, PC and so on. Also, cooling system using thermoelectric module consists of heat sink, cooling pan, cooling plate and thermoelectric module in order to make the cooling region as shown in Fig. 2. The size of thermoelectric module(Model:HM6040, AceTec, Inc.) was $40\text{mm} \times 40\text{mm} \times 4.0\text{mm}$ (width \times depth \times height), respectively. Thermoelectric module received 7V to operate from DC power source, and its performance specifications were shown in Table 1[7]. The heat sink was used for cooling the hot side of thermoelectric module, and its size was $190\text{mm} \times 125\text{mm} \times 40\text{mm}$ (width \times depth \times height).

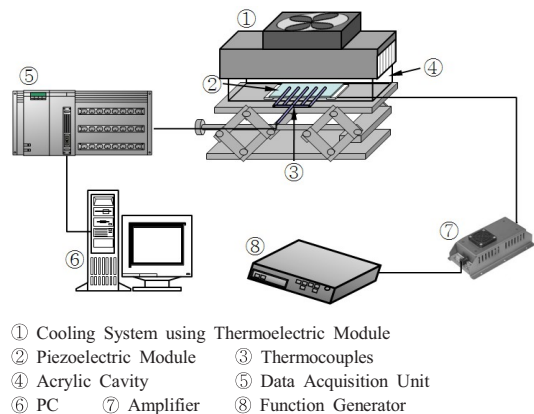
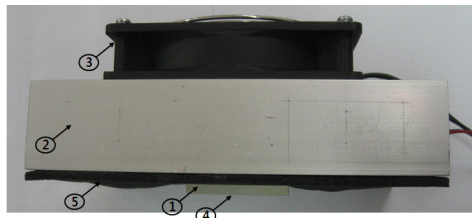


Fig. 1. Experimental set-up for temperature measurement



① Thermoelectric Module ② Heat Sink
③ Cooling Pan ④ Cooling Plate ⑤ Heat Insulator

Fig. 2. Photograph of cooling system using thermoelectric module

Table 1. Specifications of thermoelectric module

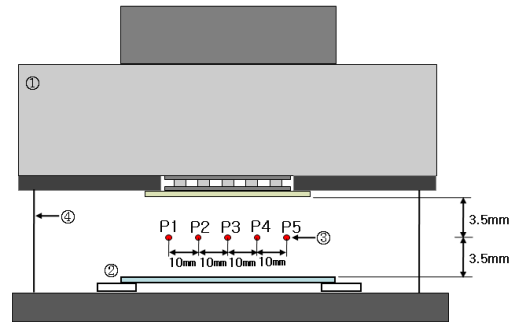
Model		HM6040
Spec.	Q_{max}	51.4W
	I_{max}	6.0A
	V_{max}	15V
	ΔT_{max}	70℃
	Weight	23.21g

The cooling fan was also used for cooling the hot side of thermoelectric module, and it received 12V to operate. The cooling plate was used for reducing thermal loss and improving thermal conductivity between the hot side of thermoelectric module and heat sink.

The size of piezoelectric module(Model:503-DQM, Piezo System, Inc.) and the performance specification was shown in Fig. 3 and Table 2, respectively[8]. It was used to generate compulsive convection in the cold region of the cooling system using thermoelectric module. As shown in Fig. 4, it was located under the thermoelectric module with 7mm gap. Five (T-type) thermocouples were located at 3.5mm height from the piezoelectric module to measure the temperature in the cold region, and the distance between each thermocouple was 10mm. The cold region was made and sealed by acrylic cavity.

Table 2. Specifications of piezoelectric module

Model		503-DQM
Spec.	Resonance Frequency	52Hz
	Rated Voltage	$\pm 90V_p$
	Blocked Force	$\pm 3N$
	Stiffness	188N/m
	Free Deflection	$\pm 1,600\mu m$
	Capacitance	232nF
	Weight	10.4g



① Cooling System using Thermoelectric Module
② Piezoelectric Module
③ Measurement Points ④ Acrylic Cavity

Fig. 3. Schematic diagram of temperature measurement points

The temperature in the cold region was measured during 7 minutes from initial time when the piezoelectric module wasn't and was operated with frequency of 80Hz and 110Hz after the temperature stabilization. The measurement data was automatically saved every half second by PC through the data acquisition unit. The experiment was performed three times to obtain the accurate results.

The coefficient of performance was calculated by the measured temperature data and its formula was as shown in Eq. 1[9]. In this study, the coefficient of performance was only considered the temperature result because this study focused on temperature distribution. where T_1 and T_2 is the average temperature of cold region of cooling system using thermoelectric module with and without piezoelectric module, respectively.

$$COP(\beta) = \frac{Q_1}{Q_1 - Q_2} = \frac{T_1}{T_1 - T_2} \quad (1)$$

2.2 Experiment for thermo-flow phenomena

As shown in Fig. 5, the experimental set-up for thermo-flow visualization consisted of the cooling system using thermoelectric module, piezoelectric module, He-Ne laser(35mW), CCD camera(XC-HR300, Sony Inc.), image grabber(Meteor-IIC4, Matrox Inc.), PC and so on. The cold region between the thermoelectric and piezoelectric modules was sealed by

an acrylic cavity, and the cavity was filled with smog. Also, the emitted laser beam from the He-Ne laser was changed for plane laser beam via the optic lens to make test section, and the CCD camera was located vertically with test section. The thermo-flow phenomena in the cold region of cooling system using thermoelectric module were recorded when the piezoelectric module wasn't and was operated. The results of visualization were saved as image files through the image grabber and were analyzed by Matrox Inspector 8.0.

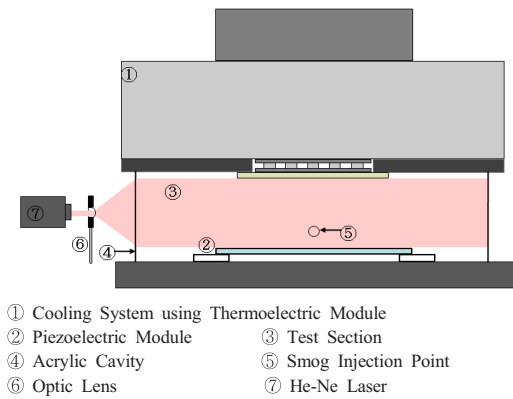


Fig. 5. Experimental set-up for thermo-flow visualization

3. Result and Discussion

3.1 Result of the temperature measurement

The temperature distributions in the cold region of cooling system using thermoelectric module were measured from initial time to 420 seconds, when piezoelectric module wasn't and was operated and its result shows in Fig. 6. Also, the temperature distributions in cold region of cooling system using thermoelectric module were measured during same time, when piezoelectric module was operated with applied frequency of 80Hz and 110Hz after 300 seconds from initial time and its results show in Fig. 7 and Fig. 8, respectively.

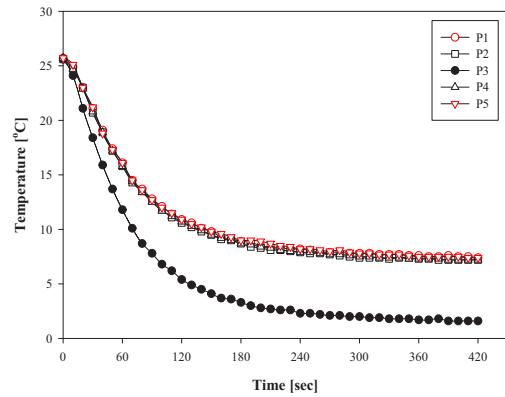


Fig. 6. The result of temperature distribution on operated only cooling system using thermoelectric module

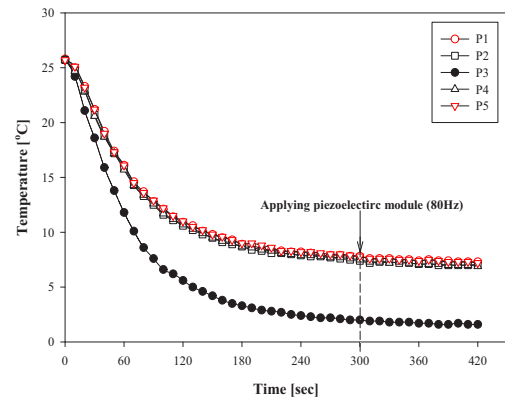


Fig. 7. The result of temperature distribution on operated cooling system using thermoelectric module with piezoelectric module as frequency of 80Hz

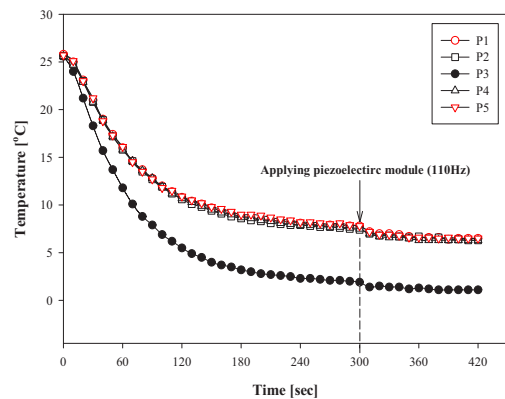


Fig. 8. The result of temperature distribution on operated cooling system using thermoelectric module with piezoelectric module as frequency of 110Hz

As shown in Figs. 6 ~ 8, the temperature distributions at all points were rapidly reduced from initial time to about 180 seconds, and then the temperature distributions were stable and were not almost reduced after about 240 seconds. The measured temperature was 25.7°C at the initial time. The temperature at center point(P3) was lower than other points, and the temperatures at the left and right sides point(P1 and P5) were higher than the other points.

In Fig. 6, the measured temperature at P3 was about 1.6°C after 420 seconds, and the measured temperatures at P1 and P5 were about 7.4°C after the same time. Also, the average temperature was about 6.2°C after 420 seconds. From the measured temperature, the coefficient of performance was about 1.32. In Fig. 7, the measured temperature at P3 was about 1.6°C and the measured temperatures were about $7.2 \sim 7.3^{\circ}\text{C}$ at P1 and P5 lower than the result of measured temperature in Fig. 6. The average temperature was about 6.0°C after 420 seconds and the coefficient of performance was about 1.30. In Fig. 8, the measured temperature at P3 was about 1.1°C and the measured temperatures were about 6.5°C at P1 and P5 lower than the result of measured temperature in Fig. 6. The average temperature was about 5.3°C after 420 seconds and the coefficient of performance was about 1.26.

3.2 Result of the thermo-flow visualization

Fig. 9 shows the result of thermo-flow visualization in the cold region of cooling system using thermoelectric module during 30 seconds(Fig. 9 - ①), 60 seconds(Fig. 9 - ②) and 120 seconds(Fig. 9 - ③) without operating piezoelectric module. As shown in Fig. 9, the cooling air occurred from the cooling system using thermoelectric module was converged on at the center point(P3) in cold region. After passed time, the circulation phenomena was occurred by natural convection at the edge of both sides in cold region. This result was proved by measured temperature distribution as shown in Fig. 6.

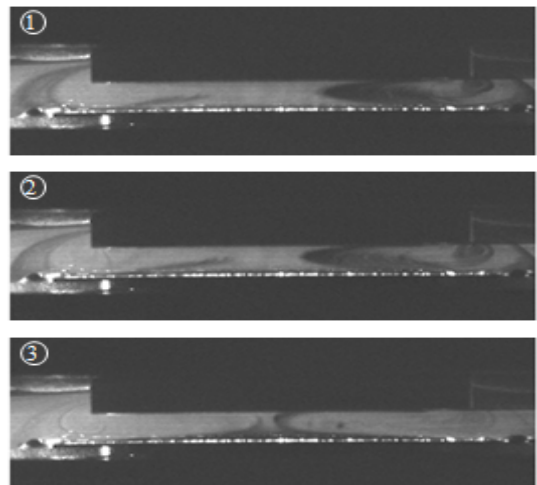


Fig. 9. Visualization of thermo-flow without piezoelectric module during from initial time to ①30 seconds, ②60 seconds and ③120 seconds, respectively.

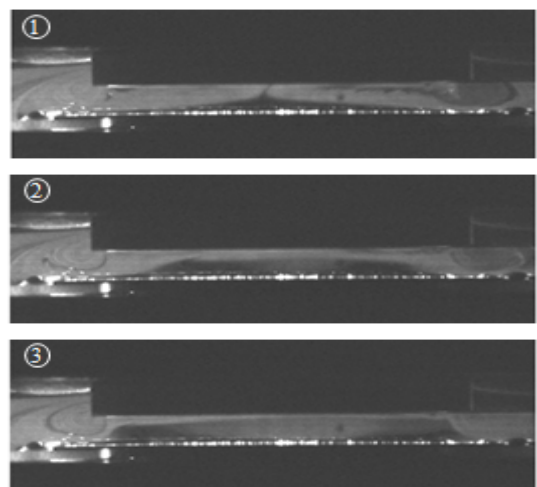


Fig. 10. Visualization of thermo-flow with piezoelectric module during from initial time to ①300 seconds, ②330 seconds and ③360 seconds, respectively.

Fig. 10 shows the result of thermo-flow visualization in the cold region of cooling system using thermoelectric module when the piezoelectric module was operated with frequency of 110Hz after 300 seconds from the initial time. As shown in Fig. 10, when the piezoelectric module was operated in test section, the cooling air was actively circulated in cold

region because impulsive convection was generated by the vibration from piezoelectric module. In the end, the measured temperatures at all points were reduced by the impulsive convection flow and this results were also proved by the results of measured temperature distribution as shown in Fig. 7 and Fig. 8.

4. Conclusion

This study experimentally investigated on improving of the cooling performance of cooling system using thermoelectric and piezoelectric modules in cold region. The main conclusions from the results of this study can be summarized as follows;

1. The results of temperature measurement and coefficient of performance revealed that the cooling performance of cooling system using thermoelectric module was improved by the vibration of the piezoelectric module.
2. In case of operating piezoelectric module with the frequency of 110Hz, the result of cooling performance was better than that case of the frequency of 80Hz.
3. From the results of temperature measurement and thermo-flow visualization, the vibration induced by the piezoelectric module generated the impulsive convection in cold region. Therefore, the cooling performance was improved because the cooling air in cold region was actively circulated by the impulsive convection flow.

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