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Optimization of the Array for PTC Stone by Thermal-Structural Analysis

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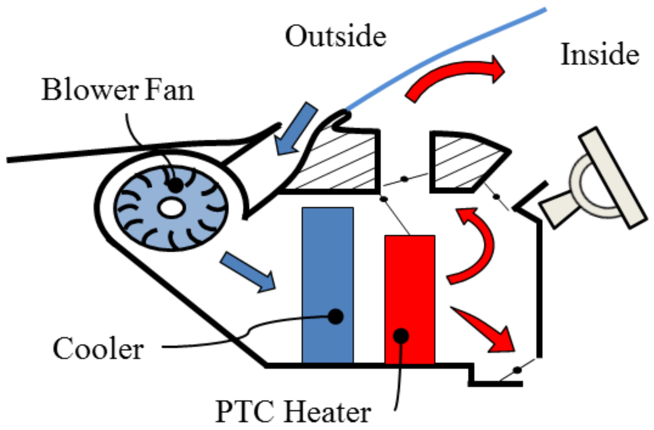
Abstract
Since electric vehicles have no engine noise, the overall noise level is reduced, causing other sources of noise to become more audible. Component development has been implemented to resolve this use. PTC heaters in electric vehicles produce low noise due to local thermal deformation of the PTC stone array. This study analyzed the correlation between the thermal deformation of radiating fins in a PTC heater and factors of the PTC stone array. After setting key design factors, full factorial design in the design of experiments was applied, and a thermal-structural analysis was conducted on 27 simulations. Main effects were analyzed using simulation results, and factors having the most influence in decreasing order were overlap distance between PTC stones, distance between PTC stones, and thickness of PTC stones. To minimize thermal deformation, an optimization array was derived based on these findings.

Keywords: PTC Heater, PTC stone, PTC stone array, Design of Experiment (DOE), Thermal-Structural Analysis, Thermal deformation minimization.

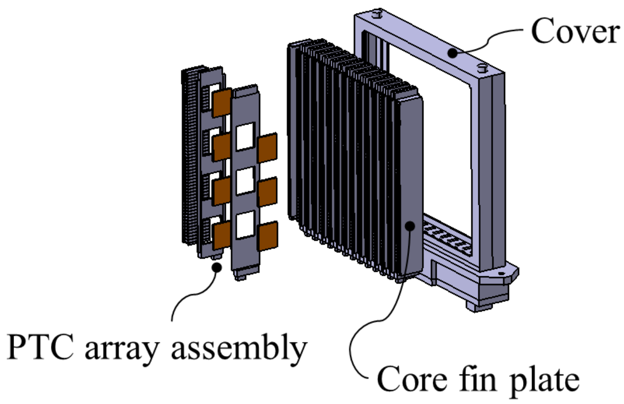
1. Introduction
Recently, exhaust gas has come under the spotlight as a major cause of environmental problems such as air pollution and global warming. As such, there has been increased demand for electric vehicles, which are an environmentally-friendly means of transport having the same performance as vehicles with internal combustion engines. [1]
A heating ventilation and air conditioning (HVAC) system is required since electric vehicles cannot use the heating system of the internal combustion engine. This led to the development of an intelligent PTC heater, which improves heating performance and reduces weight by simplifying the heating system and combining direct heating of air. [2]
Because Positive Temperature Coefficient (PTC) stones serve as a heat source in the PTC heater, researchers have examined the structure of PTC stones in order to achieve precise control of the heating temperature. [3] Battery consumption is increased when the driver turns on the PTC heater while driving, and the distance that can be traveled drops significantly. Some research has focused on applying Pulse Width Modulation (PWM) switching to divide up the power, thereby enabling electric vehicles to travel a longer distance from one charge cycle. [4] To reduce ripple current for introduction of PWM control to vehicles, the PWM switching frequency must be raised. An increase in PWM switching frequency is problematic as it causes a proportional increase in the noise level of the PTC heater. [5] Fault Tree Analysis (FTA) on noise factors in the PTC heater showed that the PTC array was the most significant factor contributing to noise. [6]
The array of PTC stones affects interference between PTC stones and the density of thermal energy. This imbalance of thermal energy leads to increased local thermal deformation of radiating fins, which in turn causes noise due to friction movement between radiating fins and the case. Array optimization of PTC stones is essential to prevent this issue.
Against this backdrop, this study observed trends in deformation while modifying the PTC stone array to obtain an optimization model that minimizes local thermal expansion. The distance between PTC stones, overlap distance between PTC stones, and thickness of PTC stones were set as independent variables. Among the design of experiments, full factorial design was used to establish an experimental plan for 27 simulations with three levels for the three selected factors. Simulations were performed under a thermal-structural analysis, and the thermal deformation of radiating fins was analyzed. Variance analysis in the statistical software Minitab revealed that the output variables were independent of one another and followed a normal distribution. The factors influencing thermal deformation were determined using a main effect analysis. By applying the level causing the least deformation for each factor, an optimized array that minimizes overall thermal deformation was derived.

2. Thermal-Structural Analysis
2.1 PTC Heater Modeling
The heating system in an electric vehicle uses a turbine to bring in external air to inside the car, and the air is heated as it passes the PTC heater of the HVAC system.
Fig. 1 shows the structure of the PTC heater, which consists of a cover, core fin plate, and a PTC array assembly. The cover is fixed on the HVAC, and the PTC array assembly releases thermal energy produced by PTC stones. The two ends of the PTC array assembly are fixed by the core fin plate.
The model used in simulations had a PTC array assembly. Fig. 2 shows the key components of the PTC array components. The PTC stone is used as a heat source and the

insulator fixes the array, while the radiating fins release thermal energy produced by the heat source. When the deformation of radiating fins is large, frictional movement between radiating fins and the case may generate audible noise.



(a) HVAC system of electric vehicle



(b) PTC heater for HVAC system

Fig.1. The structure of (a)HVAC system and (b)PTC heater

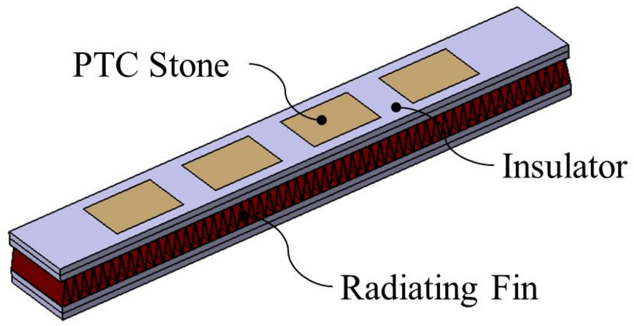


Fig.2. The structure of analysis model

2.2 Simulation Conditions

Fixed supports were introduced to the left and right sides of the analysis model since each component is confined by surface contact. The PTC stone was subject to a heating temperature of 150℃, and radiating conditions were applied to radiating fins. The hex dominant method was employed for the mesh, and node connections were examined after dividing the entire model by 2 mm.

Through the thermal-structural analysis, observations were made of the deformation of radiating fins, and the y-axis displacement was analyzed as deformation (dh_y).

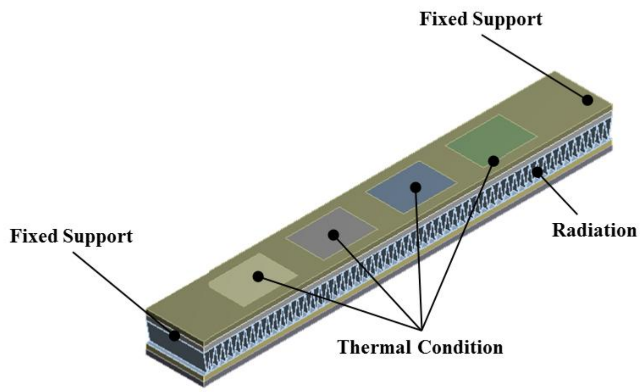


Fig.3. Boundary condition

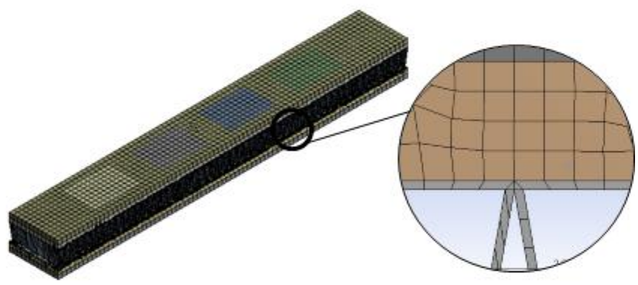


Fig.4. Mesh system of PTC array

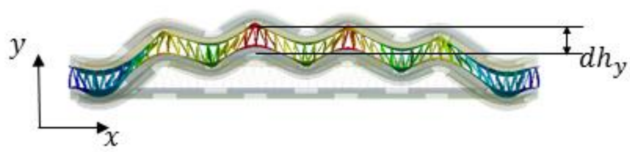


Fig.5. Result of simulation

3. Optimization of PTC Stone Array Using Design of Experiments

3.1 Full Factorial Design

The design of experiments, performed at all combinations of levels, can analyze main effects as well as the effects of interactions. It is useful in determining the characteristics of factors or obtaining the optimal combination of levels.

To analyze the effects of design factors for the PTC stone array, this study selected overlap distance between PTC stones (q), distance between PTC stones (p), and thickness of PTC stones (t). The structure is shown in Fig. 6.

TABLE.1. Parameters and levels for analysis

Factor	Level		
	1	2	3
Distance between PTC stones: p(mm)	32	37.2	42.4
Overlap distance between PTC stones : q(mm)	3	6	9
Thickness of PTC stone: t(mm)	4	4.4	4.8

TABLE.2. $L_{27}(3^3)$ Orthogonal array for analysis

No.	Factor		
	1	2	3
1	32	3	4
2	32	3	4.4
3	32	3	4.8
4	32	6	4
5	32	6	4.4
6	32	6	4.8
7	32	9	4
8	32	9	4.4
9	32	9	4.8
10	37.2	3	4
11	37.2	3	4.4
12	37.2	3	4.8
13	37.2	6	4
14	37.2	6	4.4
15	37.2	6	4.8
16	37.2	9	4
17	37.2	9	4.4
18	37.2	9	4.8
19	42.4	3	4
20	42.4	3	4.4
21	42.4	3	4.8
22	42.4	6	4
23	42.4	6	4.4
24	42.4	6	4.8
25	42.4	9	4
26	42.4	9	4.4
27	42.4	9	4.8

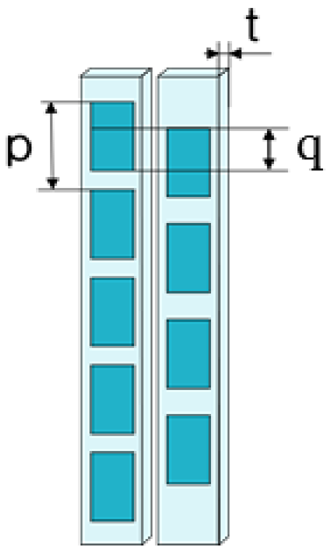


Fig.6. Design factors of PTC array

In general, 5 kW heaters are used in electric vehicles. This radiating capacity is satisfied when one set of PTC stone array has at least 4x3 crosses but fewer than 5x4 crosses. The minimum and maximum level of the distance between PTC stones (p) was thus set as 32 (mm) and 42.4 (mm), respectively.

Thermal energy becomes concentrated when upper and lower PTC stones are overlapped. Since this leads to an increase in thermal deformation of radiating fins in the overlapped area, the overlap distance between PTC stones (q) was defined as a factor, and levels were set such that the array had symmetrical upper and lower areas. The thickness of PTC stones (t) was also a factor because thermal deformation results from heating of PTC stones. Table 1 shows the level values by factor.

A shown in Table 2, full factorial design was used while varying design factor values, and simulations were performed 27 times.

3.2 Analysis of Results

The statistical software Minitab was used to analyze the relationship between the array of PTC stones and thermal deformation. Fig. 7 shows the main effects of each factor on the thermal deformation of radiating fins. The main factors were in the order of overlap distance between PTC stones (q), distance between PTC stones (p), and thickness of PTC stones (t). Table 3 shows the results of the variance analysis, and the p-value was highly significant at 0.000. The R^2 of 91.40% and adjusted R^2 of 88.82% showed that the results were significant. Fig. 8 is the residual graph used to verify whether the simulations were properly run. The distribution of residuals is shown in the normal probability plot, in which the points are close to a linear form. From the uniformly spread distribution along the average in the Versus Fits graph, we can see that the assumption of homoscedasticity is satisfied. The bell-shaped histogram indicates that there were sufficient data for the normal distribution. The Versus Order shows a normal distribution since no specific trends were observed, thus confirming that the simulations were random.

Fig. 9 presents the analysis results for interactions. The factors exhibited independent behavior without engaging in interactions with one another.

The analysis based on design of experiments allowed predictions of values corresponding to level 1 of the overlap distance between PTC stones (q), level 3 of the distance between PTC stones (p), and level 1 of the thickness of PTC stones (t). Table 4 shows simulation results and level values by factor of both the existing model and optimization model. The optimization model achieved a 10% decrease in deformation compared to the existing model.

TABLE.3. Analysis of variance for deformation

Source	SS	MS	F	P
p (mm)	0.00003	0.000015	7.31	0.004
q (mm)	0.000389	0.000194	96.09	0
t (mm)	0.000011	0.000006	2.83	0.083
Error	0.00004	0.000002		
Total	0.00047			
S = 0.0014226	R-Sq = 91.40%	R-Sq(adj) = 88.82%		

TABLE.4. Optimal design values and deformation

Source		Optimized model
Level	P	3
	q	1
	t	1
Deformation (mm)		0.117907

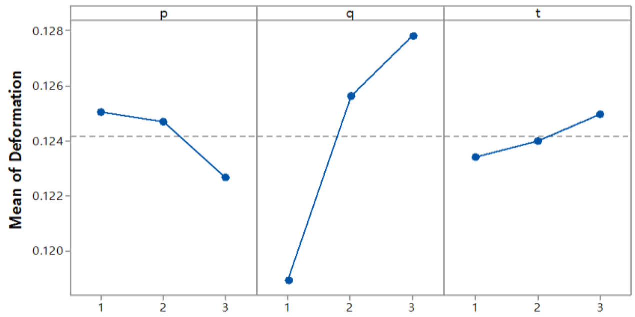


Fig.7. Main effect plot for deformation

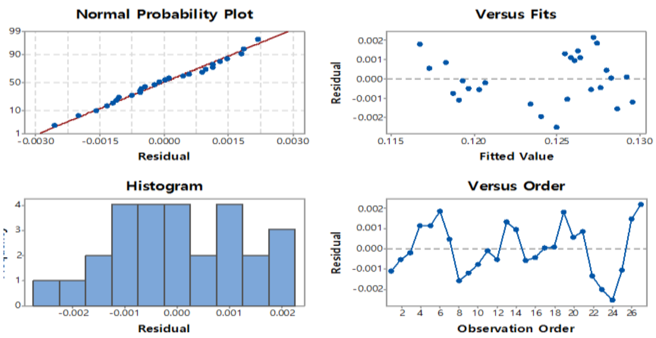


Fig.8. Residual plots for deflection

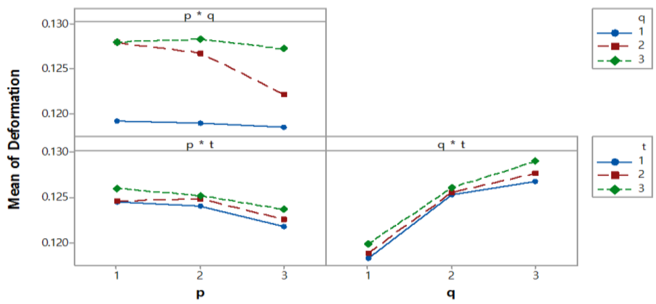


Fig.9. Interaction plot for deformation

4. Conclusion

To derive an optimization array that minimizes local thermal deformation, this study analyzed the correlation between thermal deformation and factors of the PTC stone array. An analysis of main effects showed that the factors having the most influence on deformation were overlap distance between PTC stones (q), distance between PTC stones (p), and thickness of PTC stones (t). The optimization array of PTC stones, derived to minimize thermal deformation, is expected to contribute to noise reduction in electric vehicles.

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References

[1] W. C. Yang, "Fuel Cell Electric Vehicles: Recent Advances and Challenges," International Journal of Automotive Technology, vol. 1, no. 1, pp. 9-16, 2000.

[2] C. W. Lee, S. W. Jung, "Development of PWM Intelligent-control High-voltage PTC Heater for Eco-friendly EV," Journal of the Korean Society of Automotive Engineers, vol. 33, no. 12, pp. 42-46, 2011.

[3] S. M. Park, S. D. Kim, "Development of intelligent-controlled high voltage PTC for Eco-friendly EV," KSME, pp. 144-147, 2011.

[4] S. W. Jung, "Development of PWM Intelligent-control High-voltage PTC Heater for ECO-friendly EV," Journal of the Korean Society of Automotive Engineers, 2011.

[5] H. M. Woo, "A Design of the DC-DC Converter for a PTC Heater of the Indoor Air Conditioning in the Electric Vehicle," The Transations of the Korean Institute of Electrical Engineers, 2011.

[6] S. W. Jung, " Study on the Noise Reduction Mechanism according to PWM Control in High Voltage PTC Heater for the Electric Vehicle, " Master' s Thesis, Kong-Ju university, 2015.

[7] K. Umezu, and H. Noyana, "Air Conditioning System for Electric Vehicles, i-MiEV," JSAE, 2010.

[8] T. Jibiki, M. Shima, H. Akita, and M. Tamura, " A Basic Study of Friction Noise Caused by Fretting," Wear, vol. 251, pp. 1492-1503, 2001.

[9] Alan, D. Berman, Wiliam, A. Ducker, and Jacob, N. Isr acelachvili, " Origin and Characterization of Different Stick-slip Friction Mechanisms," Langmuir, vol. 12, pp. 4559-4563, 1966.

[10] T. Mizutani, K. Iritani, S. Tsuchiya, and Y. takeo, " Air Conditioning System for Electric Vehicles," JSAE, vol. 53, no. 2, pp. 44-49, 1999.

[11] I. Horuz, and O. Kaynakli, " An experimental analysis of automotive air conditioning system," Int. Comm. Heat Mass Transfer, vol. 30, no. 2, pp. 273-284, 2003.