Hot and cool temperature control of the car-seat utilizing the thermoelectric device

Hyung-Sik Choi*,You-Shin Kim**, Jung-Jae Woo**, Chang-Hoon Jeon**

* Department of Mechanical Engineering, Korea Maritime University, Pusan, Korea
(Tel：+82-51-410-4297, E-mail: hchoi@hanaran.hhu.ac.kr)

** Department of Mechanical Engineering, Korea Maritime University, Pusan, Korea

Abstract: The thermoelectric device was applied to a car-seat to control the hot temperature in summer and cold temperature in the winter. The characteristics of the device used to a car-seat were analyzed. The air conditioning structure was designed to regulate the hot side of the thermoelectric device. To control the temperature of the car-seat, a robust control algorithm based on the sliding mode control was applied, and a controller using one-chip microprocessor was developed. The performance of the proposed controller through experiments was shown.

Keywords: thermoelectric device, robust control algorithm, sliding mode control, temperature control

1. INTRODUCTION

Nowadays, since people spend a lot of time in the car, comfortable surroundings in the car, is very important. Interior temperature in the car is a factor that influences comfortable surroundings. When we first take a seat in the car in the summer and the winter, we are displeased very much by the car-seat. We become very sensitive to the temperature from the seat. Although the heating system using hot wires in the car-seat has been used in general, but the cooling system of the car-seat has been used rarely.

The representative active device to have both hot and cool temperature on each side is the thermoelectric device. The merit of the device is that it takes a role of cooler in the summer and a heater in the winter since the temperature of the device can be hot or cool by the direction of the applied voltage. By applying voltage to the thermoelectric device, hot or cool temperature on both side of the device appears, which is called Peltier phenomenon. This phenomenon was discovered by Peltier in 1834.

A research was performed on the basic characteristic of semiconductor material and heat electromotive force[1], studies on the temperature control of the refrigerator using thermoelectric liquid cooler were performed[2][3]. And a study on the performance of the heat pump using thermoelectric phenomenon and the conventional heat pump[4], and the measurement of surface heat flux using the Peltier effect was performed[5]. In Korea, concept design was tried and analysis on thermodynamic performance of the heat pump using the thermoelectric semiconductor was performed[6], and the research on development of a waterless container utilizing thermoelectric devices was performed[7]. And control of the precision heat actuator using thermoelectric device was studied[8].

This paper is dealing with the design of hot and cool temperature control system and the control of temperature of the system to maximize the hot or cool temperature effect using thermoelectric device. We designed an air conditioner composed of an air duct to control high temperature on reverse side during cooling. We performed a research on a software and hardware of the regulator for the pleasant temperature.

The composition of the paper is that the analysis of characteristics and the performance tests of thermoelectric device were performed in chapter 2. Chapter 3 accounts for the control of temperature on reverse side and mathematical modeling for the hot and cool temperature control of the designed car-seat system. The theory on the temperature control using the sliding mode control is described under the uncertain environments and parameter uncertainties from the car-seat and thermoelectric device based on robust control. In chapter 4, the experiment and its results of the proposed controller for the car-seat are presented.

2. THE CHARACTERISTIC AND PERFORMANCE OF THERMOELECTRIC DEVICE

2.1 The principle and characteristic of thermoelectric device

The thermoelectric device is made from Bismuth Telluride (Bi_2Te_3) including small amount of impurity. It consists of negative type semiconductor which has more electrons and positive one which has fewer electrons. The thermoelectric device shows Peltier phenomenon, when heat is absorbed on one of the side and is emitted on the other side while applying electricity to conductor.

By applying voltage to the arranged N, P type semiconductor at Fig.1, the electron moves from low energy level P type semiconductor to high energy level N type semiconductor. As a consequence, heat is absorbed on the cool side, and the electron comes to P type semiconductor again and then the heat is emitted on hot side.

The performance of heat pumping is proportional to the flow of electricity and the number of pairs of semiconductor. The absorbing and the emitting side are exchanged by changing the direction of current.

Absorbed and emitted heat depends on Peltier coefficients and the intensity of an electric current. Since Peltier phenomenon grows bigger as the intensity of an electric current increases, heat conduction and the different temperature on both side of the device becomes bigger at the same time. Despite of the increased an electric current, heating value does not increase any more due to the Joule heat. It causes the opposite effect during cooling by applying more electricity to the device than its normal electric current.

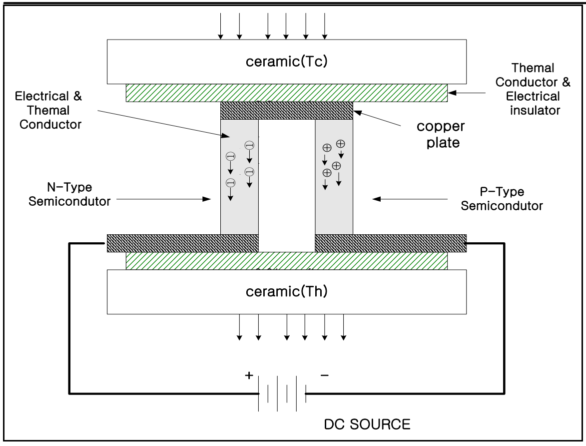

Fig. 1 the principle of thermoelectric device

2.2 The characteristic curve and the performance test of thermoelectric device

The typical thermoelectric device, HM3930 was selected to compose the hot and cool temperature control system in the car-seat and its performance was tested. It has a good cooling effect with the low intensity of currents, and maximum critical voltage is 8.4(V). Table 1 shows the specification of HM3930, and Fig. 2 shows the characteristics of temperature variation versus the variations of the voltage and the currents.

Table 1. the specification of thermoelectric device HM3930

PART NUMBER		DESCRIPTION					
No.	HM No.	Imax (A)	Tmax (℃)	Vmax (V)	Qmax (W)	Size (L*W*H)	Weight (g)
7	HM3930	3.9	69	8.4	16.7	30*30*4.7	15.1

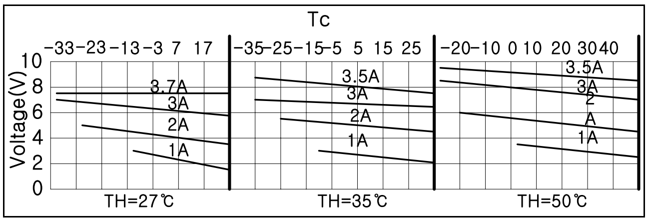

Fig. 2 HM3930 characteristics graph

We applied the thermoelectric device, HM3930, to the car-seat and took a performance test of the device to achieve cool temperature control while ventilation the hot side of the device. The device was tested by using a circular heat sink with a cooling fan on the hot side. The temperatures of the cool side and hot side were measured at the indoor temperature (25℃) by applying 5(V), and 12(V) on the thermoelectric device using electronics chip LM35 from National Semiconductor Inc. for 3 minutes.

Fig.3 shows the composed thermoelectric device, HM3930 on the heat sink with the cooling fan. Every test was conducted at the same heating and cooling condition. The test results are shown in Fig. 4.

Fig. 4(a) shows the temperature variation of the cool side through the temperature control of the hot side when input 12(V) was applied to the thermoelectric device. The currents in the conductor exceeds Imax(the maximum critical electric current) while the device inputs 12(V) are applied. As a consequence, the temperature of the hot side increases drastically, so the temperature of cool and hot side increases parallel, since heat on the hot side is conducted to the cool side. However, it is shown that the temperature of cool side is kept around 2(℃) when 5(V) input is applied since the cooling the fan cool down the hot side in Fig.4(b).

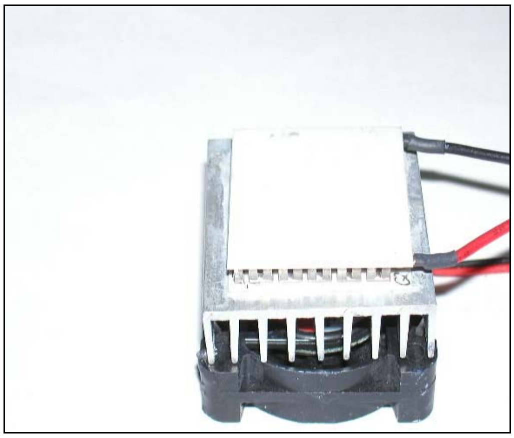

Fig. 3 thermoelectric device equipped air conditioners

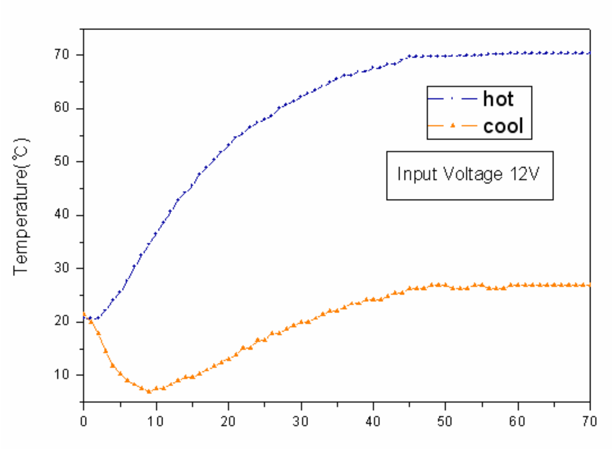

Fig. 4(a) thermoelectric device test

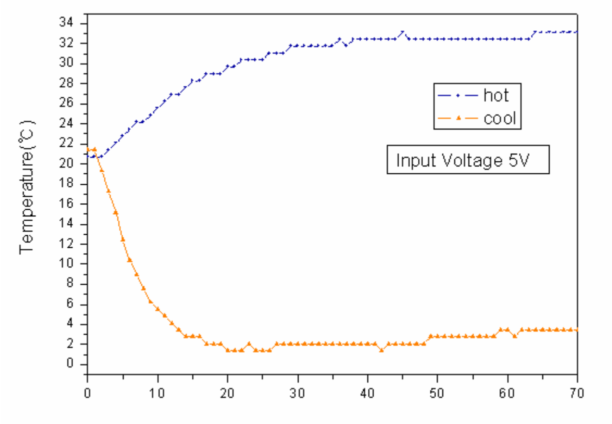

Fig. 4(b) thermoelectric device test

Through the test results, we confirmed that the capacity of the fan and a suitable input power is most important to have good cooling effect of car-seat and prevention of heat conduction between the hot and cool side.

3. THE HOT AND COOL TEMPERATURE CONTROL SYSTEM UTILIZING THERMOELECTRIC DEVICE

3.1 The development of the hot and cool temperature system and the Performance test

We designed air conditioner to control the temperature of the hot side during the other cool side. Fig. 5 shows the developed structure of air conditioner arranged with the thermoelectric devices. The wide surface of the heat sink is good for heat conduction. Cooling fan drops the temperature of the hot side by compulsory air circulation.

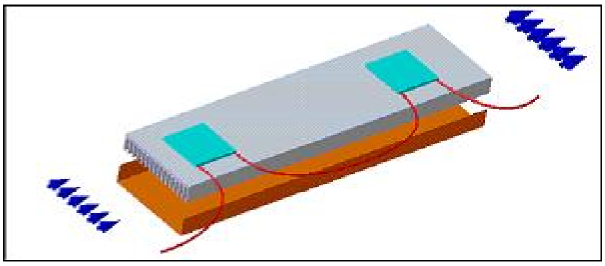

Fig. 5 the structure of air conditioner utilizing the thermoelectric devices

In order to have the maximum cooling effect in the small space of the car-seat, we developed temperature control system of the car-seat with air conditioner arranged with the thermoelectric devices. We measured two different temperatures for the performance test on developed car-seat system.

Fig.6 shows the appearance of the developed car-seat system which is used by air conditioner using the thermoelectric devices. Four of thermoelectric devices HM3930 were installed and were arranged with sufficient distance to prevent conducting heat to each other. Some insulating material was used to prevent transmitting the heat on the heat sink from the hot side to the cool side and human body. Fig. 7 is the result of the temperature test on the car-seat system. We connected two thermoelectric devices in series when the devices have input 12(V). Although it is balanced with maintained temperature between the hot and the cool side, it is able to raise temperature and to drop temperature from the external conditions easily.

Fig. 6 the appearance developed hot and cool temperature control system in the car-seat

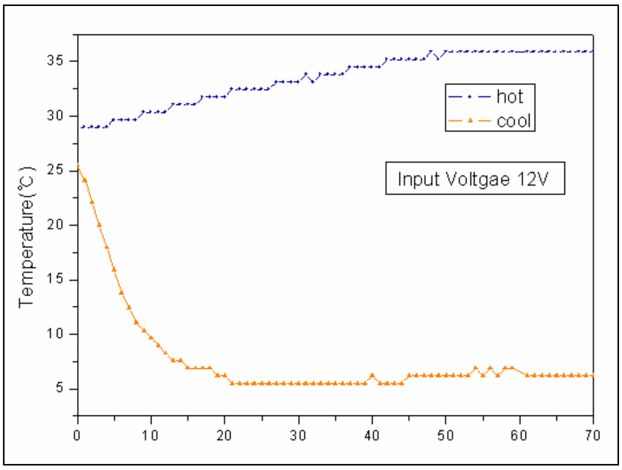

Fig. 7 an efficiency test of car-seat found hot and cool temperature control system

3.2 The modeling of hot and cool temperature system in the car-seat

It is necessary to control temperature for keeping the pleasant temperature when a man sits on the seat after installing the developed system in the car. Efficient control of temperature needs mathematical modeling. Therefore, according to the next process, the modeling of this system is performed.

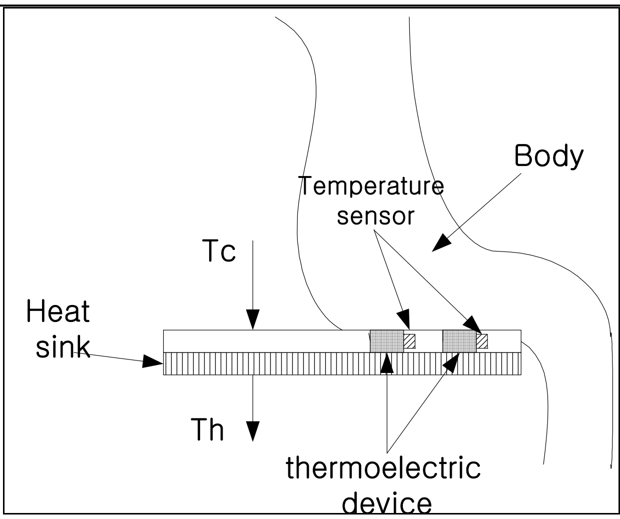

Fig. 8 the system model of car-seat

The cooling effect of thermoelectric device is a key function to determine how the sample material can be fast to cool down to a certain temperature.

$$Q_R = \alpha T_c I - \frac{1}{2} I^2 R - K_p \Delta T \qquad (1)$$

Q_R =Absorbed heat at cold device face(watt)

α = the relative Peltier coefficient ($|\alpha p - \alpha n|$),(V/K)

$\Delta T = T_h - T_c$:Temperature difference between the hot and cold sides

T_c =Temperature of cold device face

K_p =thermal conductivity of thermoelectric device [W/m·K]

Equation (1) describes the numerical expression of Peltier cooling effect of the thermoelectric device. The first term on the right hand side represents the drawing heat by Peltier effect, the second one describes the generating heat by electric current across the junction, and the last one represents the reverse conductive heat flowing from heat source to cold sink due to temperature difference of T_h and T_c .

Initially, the thermoelectric device stands thermal equilibrium with surrounding or ambient air, but soon the balance is broken by the flowing of the operating current to thermoelectric device. The equation of temperature variation with the electric current rate is expressed as follows:

While a vehicle driver is sitting on a car-seat, in Fig.8 shows the system model that the equation of temperature variation between a cold junction of device in the seat and vehicle driver can be driven by introducing the first law of thermodynamics. The first law of thermodynamics includes the convective heat transfer on the surface of device, thermal energy drawing by introducing electric current in device, and the variation of the stored energy in device. From the first law of thermodynamics, the changing rate of the stored energy in device, $\dot{E}_{st}$, can be given the following equation.

$$\dot{E}_g - \dot{E}_{out} = \dot{E}_{st} \qquad (2)$$

where $\dot{E}_g$ is the energy generation rate in the thermoelectric device, and $\dot{E}_{out}$ is the drawing rate of heat from device.

The energy generation rate, $\dot{E}_g$, in Eq.(2) induced by the applied current in device can be expressed,

$$\dot{E}_g = Q_R \qquad (3)$$

In Eq.(1) the resistance of the thermoelectric device can be so negligible due to its little value that $\dot{E}_g$ can be expressed as:

$$\dot{E}_g = \alpha T_c I - K_p \Delta T \qquad (4)$$

The energy drawing rate from the surface of the device, $\dot{E}_{out}$, in Eq.(2) is due to the convective heat transfer, and can be described as:

$$\dot{E}_{out} = K_a (T_c - T_e) \qquad (5)$$

Where K_a is the heat transfer coefficient of air, and T_c is the surrounding temperature.

The changing rate of the stored energy in the device induced by temperature variation can be expressed as:

$$\dot{E}_{st} = \frac{dU_t}{dt} = \frac{d}{dt}(\rho V c T_c) = \beta \dot{T}_c \qquad (6)$$

Where the term of $\dot{E}_{st}$ means the changing rate of thermal energy in the device, density, c, specific heat, and v, the volume of the thermoelectric device. From Eq.(1) -(6), the thermoelectric system can be expressed as the following equation.

3.3 The design of the temperature controller for the thermoelectric device

We designed the controller for the system maintaining temperature in the car-seat system including air conditioner with thermoelectric device. Although it is impossible that car–seat system is measured variable parameters exactly. The robust controller is able to apply this uncertain system.

On the research, we controlled the hot and cool temperature system by Sliding Mode Controller which is a typicality of robust controller. Fig. 9 is the configuration of control for system.

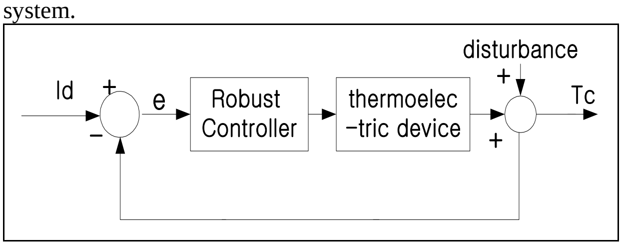

Fig. 9 the block diagram of a controller

In order to set up the controller for the system shown in Fig. 9, substituting Eq.(4),(5), and (6) into Eq. (2) yields the following equation as

$$\alpha T_c I - K_p(T_h - T_c) - K_a(T_c - T_e) = \beta \dot{T}_c \qquad (7)$$

Arranging Eq.(7) yields

$$\dot{T}_c + \frac{1}{\beta}(K_a + K_p)T_c = \frac{\alpha}{\beta}T_c I + \frac{K_a}{\beta}T_e - \frac{K_p}{\beta}T_h \qquad (8)$$

Eq.(8) can be rearranged as

$$\dot{T}_c + \alpha T_c = \zeta T_c I + \alpha T_e + \gamma T_h \qquad (9)$$

where $\alpha = \frac{K_a}{\beta}, \zeta = \frac{\alpha}{\beta}, \gamma = \frac{K_p}{\beta}$

Eq. (9) represents the mathematical modeling on the temperature change of the car-seat including the thermoelectric device actuator. In this system, α, ζ are uncertain parameters to identify the actual value. In order to control the uncertain system expressed as Eq. (9), a sliding mode control is designed as

$$I = \frac{1}{\hat{\zeta}T_c}(u_r + \hat{\alpha}T_e) - K_D \operatorname{sgn}(s) + \hat{\gamma}T_h \qquad (10)$$

where $.\hat{\zeta}, \hat{\alpha}$, and $\hat{\gamma}$ are the estimates of ζ, α , and $.\gamma$, respectively. In Eq. (10), the sliding mode s is expressed as

$$s = \dot{e} - \Lambda e \qquad (11)$$

where $e = (T_c - T_{cd})$, $u_r = \dot{T}_{cd} - \wedge e$.

In Eq.(11), $.\dot{T}_{cd}$ is the desired temperature of T_c , and . $\wedge$ is the control gain of the sliding mode controller. Substituting Eq.(10) into Eq. (9) yields

$$\dot{T}_c + \alpha T_c = \frac{\zeta}{\hat{\zeta}}(u_r - \hat{\alpha}T_e - \hat{\gamma}T_h) - K_D \operatorname{sgn}(s) \qquad (12)$$

Arranging Eq. (12) yields

$$\dot{e} - \Lambda e = \left\{ \frac{\hat{\zeta} - \zeta}{\hat{\zeta}}(\dot{T}_{cd} - \wedge e + (\alpha - \hat{\alpha})T_c) \right\} - K_D \operatorname{sgn}(s) \qquad (13)$$

where K_D is the control gain, and $\operatorname{sgn}(s)$ is defined as

if s>1 , sgn(s) = +1,
if s<1, sgn(s) = -1,

$$K_D > \left| \frac{\hat{\zeta} - \zeta}{\hat{\zeta}}(\dot{T}_{cd} - \wedge e + (\alpha - \hat{\alpha})T_c) \right| \qquad (14)$$

If K_D is defined as Eq. (14), the closed-loop system becomes stable such that T_c converges to T_{cd} . As a result, the desired temperature can be achieved.

4. THE TEST OF HOT AND COOL TEMPERATURE CONTROL SYSTEM

4.1 The configuration of controller

The hardware configuration for the test of the hot and cool temperature control in car-seat system is shown in Fig. 10. Fig.11 shows the developed hardware system which is made by the hardware configuration. Actuate driver of thermoelectric device consists of H-bridge current used by FET to control the current direction. Time delay controller has roles to reduce the damage of driver and semiconductor from over-current while the current direction changes. PIC16F873 is used as a sort of One-Chip μ -Processor, CUP. The source of input power in the device is 12(V), and temperature sensor is LM35. It follows the setup temperature, when we handle the cooling switch or heating one.

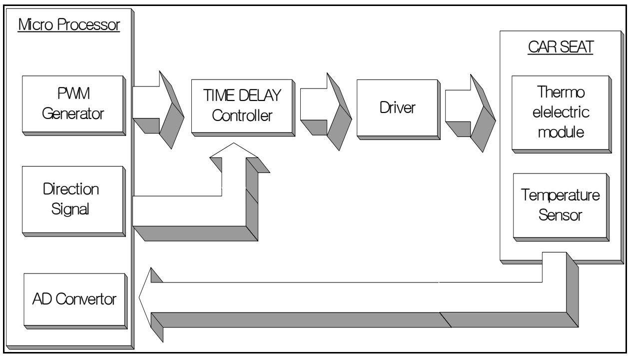

Fig. 10 the hardware configuration for experiment

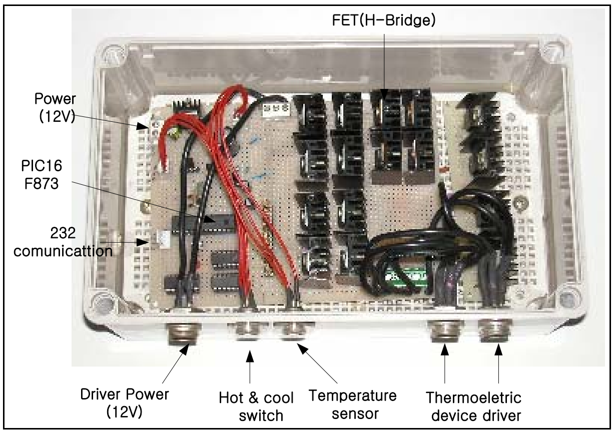

Fig. 11 the hardware of controller and driver

4.2 The test of the temperature control used by robust controller

The temperature control was tested the car-seat system by using robust controller. Actually, a man sat on the car-seat on this test. According to Fig.12, the goal of cooling temperature when people feel cool is 10(℃). Cooling temperature which is convergent is controlled around 10(℃). Fig.13 shows controlled convergent about 50(℃) , if the goal of heating temperature is set, 50(℃). Although it has a little over-shoot and under-shoot, it follows the goal temperature through the controller.

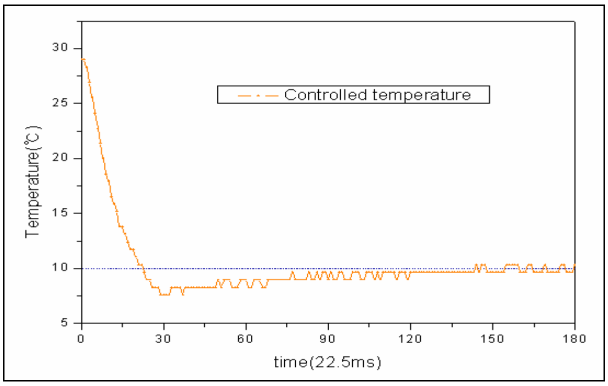

Fig. 12 the temperature control of the goal temperature 10(℃)

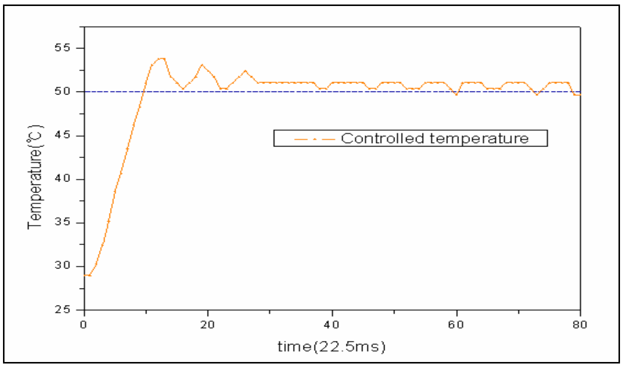

Fig. 13 the temperature control of the goal temperature 50(℃)

5. CONCLUSION AND CONSIDERATION

This paper describes the design of the car-seat with cooling and heating function, and the result of temperature control of the car-seat system utilizing the thermoelectric device. Through the performance test of the thermoelectric device, to maximize the cooling ability, it was known that the temperature of the hot side should be controlled using air conditions system.

We developed a car-seat system including air conditioner for the temperature control of the hot side, and performed modeling of the system with uncertain parameters to control of hot and cool temperature of the car-seat system. The control of the system was developed based on the one-chip µ_processor, and then it was applied to the system using the sliding mode controller. According to the test result, a successful control of the hot and cool temperature of the car-seat system was verified despite uncertain parameters of various circumstances.

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