

Temperature Control using Peltier Element by PWM Method

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Abstract: This paper presents the temperature control of aluminum plate by using Peltier element. Peltier effect is heat pumping phenomena by electric energy as one of the thermoelectric effect. So if current is charged to Peltier element, it absorbs heat from low temperature side and emits heat to high temperature side. In this experiment, Peltier element is used to control the temperature of small aluminum plate with current control and operating cooling fan only while cooling duration. Operating cooling fan only while cooling duration is proper to get more rapid heating and cooling duration. As a result of experiment, it takes about 100sec period to repeating temperature between 35°C and 70°C and about 80sec from 40°C to 70°C in ambient air temperature 25°C and while operating cooling fan only in cooling duration. Future aim is to apply this temperature control method in actuating SMHA(special metal hydride actuator) which is applicable in Siver project acting in low frequency range by using Peltier element for heating and cooling.

Keywords: Peltier element, Seebeck effect, Thermoelectric element, Thermo-electromotive force, Special metal hydride actuator(SMHA) , Pulse width modulation(PWM).

1. INTRODUCTION

As one of the thermoelectric effect, Peltier effect is heat pumping phenomena which absorbs heat from low temperature side and emits heat to high temperature side. Research of Peltier effect had begun in the early 1900s and now it has developed can be achieved up to 10% conversion efficiency. Peltier element is composed of P, N-semiconductors by II-type connection which is connected serially in the view of electricity and parallel in the view of thermodynamics. Thermoelectric effect can be categorized into Seebeck effect, Peltier effect and Thomson effect. Peltier effect is widely used in the application of aerospace, bionics, electronics. Now DOE, NASA, Hi-Z and SERI in USA and Tohoku Univ., Tokyo Univ. and Yamakuchi Univ. in Japan has making research actively in the application of thermoelectric cooling and electric generation by use of Peltier element.

In this paper, temperature control of aluminum plate by using Peltier element was investigated with given temperature range. Current control of Peltier element is achieved by using PWM method with feedback control. With repeating sequence of temperature range 40°C to 60°C, the period is about 80sec and 35°C to 70°C about 100sec.

2. BASIC PRINCIPLES

If electric potential difference exists between two metals, electron in metals moves and the kinetic energy of electron achieved from metals as thermally in Peltier element. So, Peltier element can pump heat between two metals when

current flows and as reversible, Seebeck effect is that if there exists temperature difference, current flows between two metals. As shown in Fig. 1, P, N-semiconductors are connected serially in view of electricity and parallel in view of thermodynamics. If N-type semiconductor connected to plus and P-type semiconductor connected to minus, current flows from N-type semiconductor to P-type semiconductor and this results in absorbing heat from lower side electrode and emitting heat to upper side electrode[6-7].

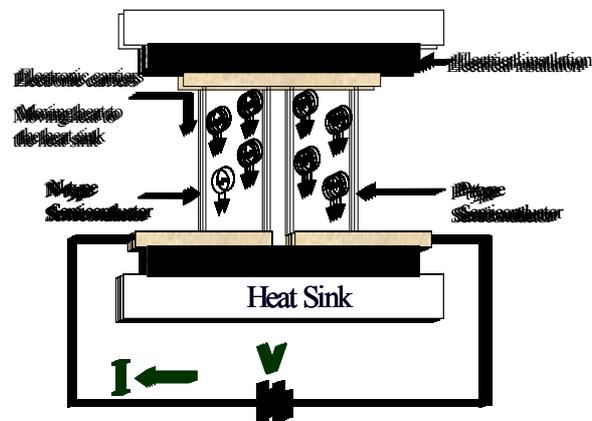


Fig.1 The operating principles of a thermoelectric cooling module.

This is a kind of heat pumping phenomena, and it is called as Peltier effect and its reversible effect is called Seebeck effect. The amount of heat pumping of Peltier element is proportional to the charging current as in Eq. (1).

$$Q = \pi I, \quad (1)$$

where, π is a Peltier coefficient and it is related with cooling and heating capacity at the junction of metal as in Eq.(2) and coefficient of Seebeck is in Eq. (3).

$$\pi = \pm(\varepsilon_c - \varepsilon_F + e\kappa_B T) / q, \quad (2)$$

$$\pi = \alpha T, \quad (3)$$

where, α [volt/K] is Seebeck coefficient, and $(\varepsilon_c - \varepsilon_F)$ is mean value of kinetic energy, T is the temperature difference between each side of Peliter.

If hot side temperature is T_h and cold side temperature is T_c , heat generated on hot side is $\alpha_e IT_h$, and heat absorbed on cold side is $\alpha_e IT_c$, where α_e is summation of Seebeck coefficients of P, N semiconductor $\alpha_e (= \alpha_p + |\alpha_n|)$. If current I is charged on Peltier element, heat generated by Joule's effect is $I^2 r_e$, where r_e is the summation of ohmic resistance of P, N semiconductor $r_e (= r_p + r_n)$. And it is assumed that half of Joule's heat flows to hot side and cold side respectively. If summation of thermal conductivity of P, N semiconductor is $k_e (= k_p + k_n)$, and then heat is transferred from hot side to cold side as amount of $k_e(T_h - T_c)$.

If n is the number of thermo-electric cooler module in Peltier element, heat absorption on low temperature side equals to Eq. (4) and heat generation on hot side equals to Eq. (5).

$$|Q_c| = n \left\{ \alpha_e IT_c - \frac{I^2 r_e}{2} - k_e (T_h - T_c) \right\}, \quad (4)$$

$$Q_h = n \left\{ \alpha_e IT_h + \frac{I^2 r_e}{2} - k_e (T_h - T_c) \right\}, \quad (5)$$

where, voltage(V), consuming power(W) and performance factor(COP) of Peltier element are equal to Eq. (6), Eq. (7) and Eq.(8), respectively.

$$V = n(Ir_e + \alpha_e \Delta T_{hc}), \quad (6)$$

$$W = nI(Ir_e + \alpha_e \Delta T_{hc}), \quad (7)$$

$$COP = \frac{|Q_c|}{W} = \frac{\alpha_e IT_c - I^2 r_e / 2 - k_e \Delta T_{hc}}{I^2 r_e + \alpha_e IT_{hc}}. \quad (8)$$

By use of cooling and heating phenomena of Peliter element, temperature control of aluminum plate is possible with current control of Peltier element. Current control of Peltier element is achieved by PWM method with feedback control.

3. EXPERIMENTS

The picture and block diagram of experimental system is shown in Fig. 2, Fig. 3 and Fig. 4. Peltier elements are attached at each side of aluminum plate whose size of 40mm×40mm×3mm as shown in Fig. 3 and temperature sensor LM35DZ are also located at aluminum plate. At other side of Peltier element, heat sinks are connected and cooling fans are attached at each heat sink.

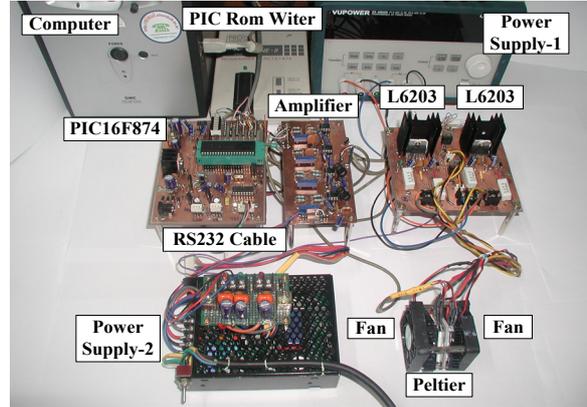


Fig. 2 Experimental apparatus.

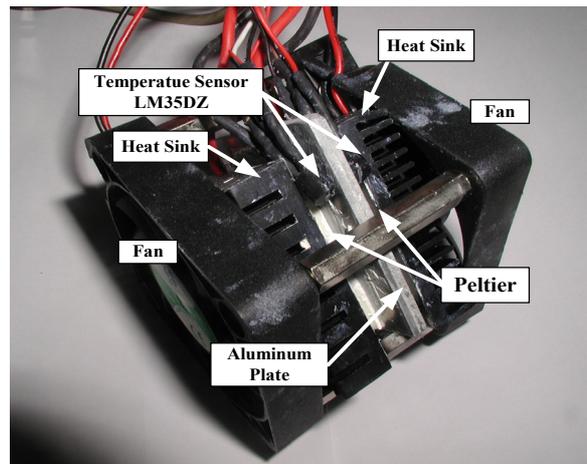


Fig. 3 Peltier and its assembly.

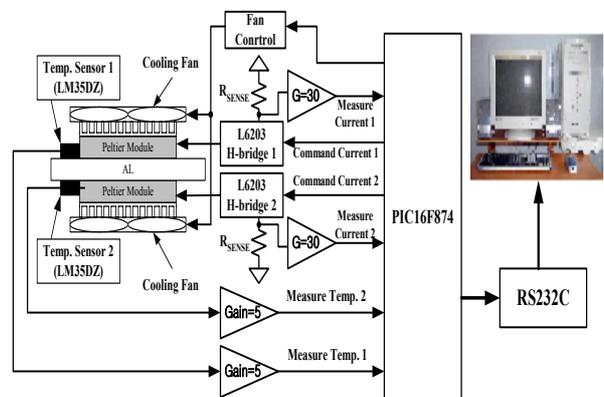


Fig. 4 Block diagram of experimental apparatus.

Current control of Peltier element is accomplished by PWM method which is generated from PIC16F874 processor and H-bridge IC L6203 switches direction of current and can drive current up to 5A to Peltier from PWM signal. R_{SENSE} , 0.1Ω is serially connected to L6203 IC and voltage between R_{SENSE} is amplified by op-amp LF356 with gain of 30 and are rectified with LC-filter. So the measured current is fed back to analog input port of PIC16F874 and PIC16F874 compare its value with reference value, so generate proper PWM signal. The resonance frequency of LC-filter in Fig. 5 is $f=1/2\pi(LC)^{1/2} = 91.8\text{Hz}$ and it is about ten times smaller with that of PWM frequency 0.976kHz and it was revealed as adequate value to rectify PWM pulse to DC voltage both in simulation and in experimentally with proper damping resistance value $R=180\Omega$.

Temperature sensor LM35DZ are used for temperature measuring of aluminum plate and its output is amplified by op-amp LF356 with gain of 5 and fed back to analog input port of PIC16F874. The specifications of temperature sensor and Peltier module are shown in Table 1. PIC16F874 receives temperature and current sensing signals and generate PWM signal to control current of Peltier and generate signal to control of current direction and generate signal to control fan ON/OFF with programmed scheme and 1/10sec sampling time was used in this experiment. And experimental datum is send to PC from PIC16F874 by using RS232 serial communication so PC saves experimental datum into HDD. The half control circuit drawing are shown in Fig. 6 and it contains H-bridge, signal amplifier, LC-filter and fan control circuits.

Control scheme is to charge heating current to Peltier until temperature of aluminum plate increase up to predetermined high temperature and then changing current direction and charge cooling current to Peltier with operating cooling fan until temperature of aluminum plate decrease down to predetermined low temperature. With repeating this sequence, temperature variation is monitored to investigate heating and cooling ability of aluminum plate by using Peltier element. And ambient air temperature during experiment was 25°C .

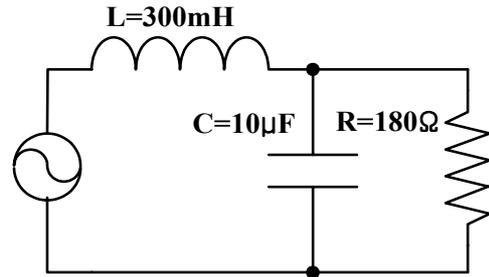


Fig.5 LC-filter to rectify PWM pulse current sensing.

Table 1. The specifications of temperature sensor and Peltier modules.

Peltier Module		Temperature Sensor	
Thermotron TS-10-127-13		National Semiconductor LM35DZ	
size	30×30×3.8	range	-55℃~150℃
maximum voltage	16.2V	output voltage	+10mV/℃
maximum current	4.5A	accuracy	0.5℃(at25℃)
maximum temperature	71℃	nonlinearity	typ. ±0.25℃

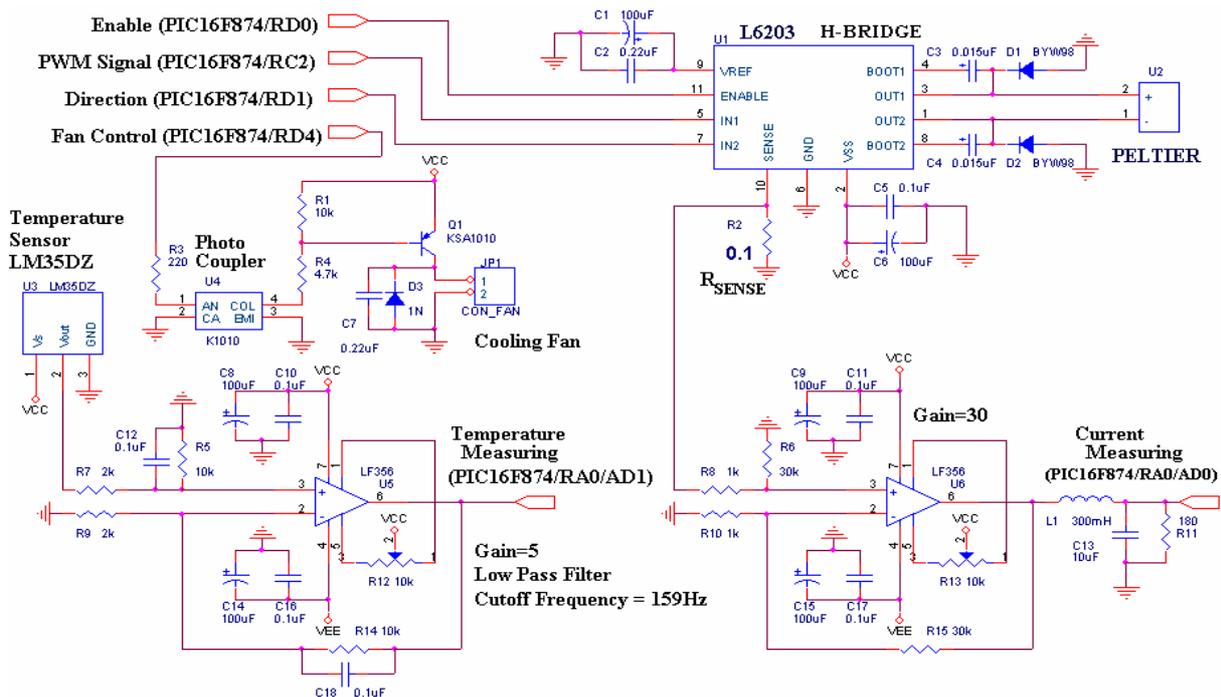


Fig. 6 Circuit drawing of control system.

4. RESULTS

4.1 Effects of cooling fan

To investigate the effect of cooling fan, temperature variation was measured within temperature range 40°C~60°C while changing cooling fan operation. Fig. 7 shows the results according to the cooling fan operation. Solid line in Fig. 7 shows the results of temperature variation while cooling fan is operated only cooling duration and dotted line shows the results of temperature variation while cooling fan is operated both heating and cooling duration. In this result, the variation of temperature is more rapid while cooling fan is operated only cooling duration, so it reveals that it is proper to operate cooling fan only while cooling duration.

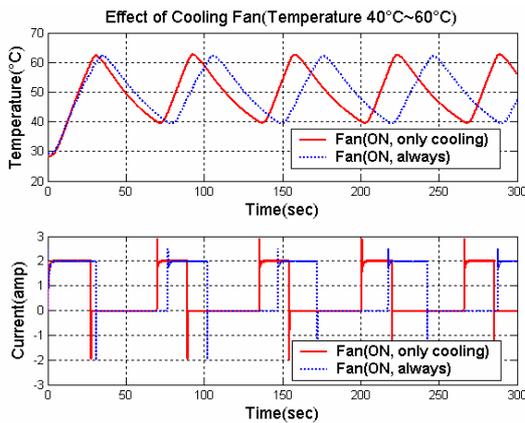


Fig. 7 Temperature variation according to fan operation.

4.2 Results of temperature control

Temperature control between 40°C to 60°C, are shown in Fig. 8 with heating current 3.0A and cooling current 0.0A while cooling fan is operated only while cooling duration. And commanded current and measured current are drawn simultaneously with comparison and to observe control performance. The repeating period of Fig. 8 with temperature range 40°C to 60°C is about 80sec. When temperature of aluminum plate reaches up to predetermined high temperature, current is switched in opposite direction and cooling current is charged to Peltier with operating cooling fan and cooling is operated until temperature of aluminum plate decrease down to predetermined low temperature.

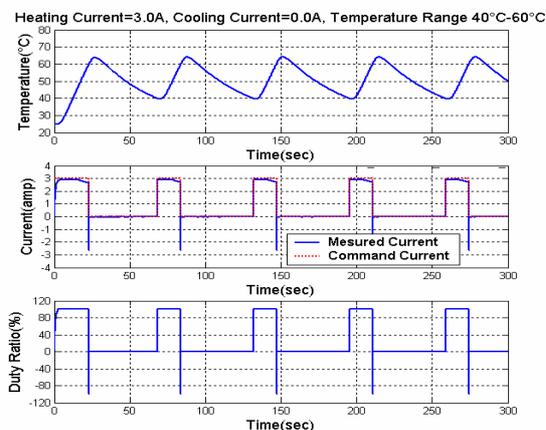


Fig.8 Temperature control from 40°C to 60°C.

Fig. 9 shows the results of temperature control between 40°C and 70°C with heating current of 3.0A while cooling fan operate only cooling duration and Fig. 10 shows the results of temperature control between 35°C and 70°C with heating current 3.0A while cooling fan operate only cooling duration. The repeating period with temperature range 40°C to 70°C is about 90sec and with temperature range 35°C to 70°C is about 100sec.

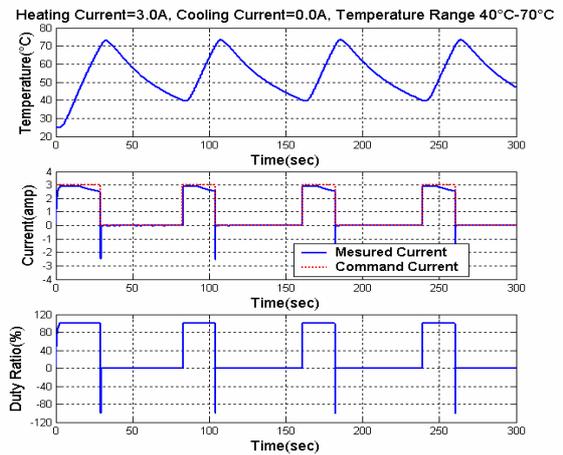


Fig. 9 Temperature control from 40°C to 70°C.

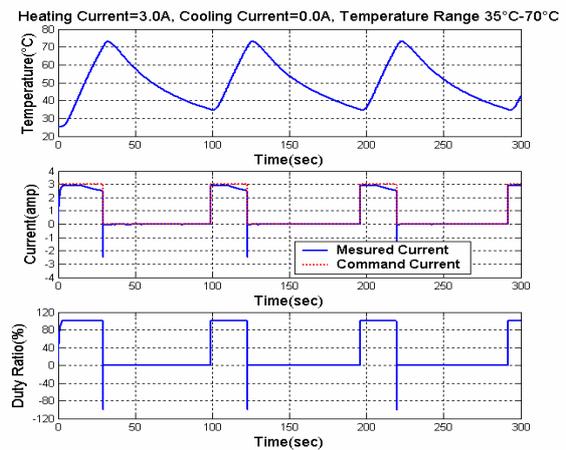


Fig. 10 Temperature control from 35°C to 70°C.

5. CONCLUSIONS

Temperature control of aluminum plate by using Peltier element are possible with given high and low temperature range. The repeating periods are depend on charging current and period is about 80sec~100sec. Future aim is to realize more rapid period of temperature control and apply this temperature control method in actuating SMHA(special metal hydride actuator) which is applicable in Siver project acting in low frequency range by using Peltier element for heating and cooling.

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