Materials Science Forum Vol. 594 (2008) pp 78-83
online at http://www.scientific.net

Development of a Constant Temperature Environment Chamber with High Stability

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Keywords: thermoelectric cooling chip, Rake's system identification method, mini environment, separation design.

Abstract. In this study, a constant temperature environment chamber with high stability is proposed. In the proposed design, the outer temperature is controlled by the air conditioner, the inner temperature is controlled by the electric current generated to control several thermoelectric cooling units. The separation design of the environment chamber from the cooling system can reduce the vibration caused by the thermoelectric cooling elements. This system adopted the Rake's System Identification Method to obtain the system model, so that optimum PID parameters can be acquired from the simulation of Matlab Simulink. The results show that the vibration can be effectively reduced and the temperature can be controlled within the range of 20±0.007°C in the steady state.

Introduction

In the area of micro/nano technologies, such as measurement, fabrication and control, the high precision temperature controlling environment is a fundamental requirement [1-4]. The NIST (National Institute of Standard and Technology, USA) invented M^3 (Molecular Measuring Machine) with the implementation of high precision environment control [5]. The BUPE (Billionth Uncertainty Precision Engineering, Korea) constructed a high precision temperature controlling chamber for UPCMM (Ultra Precision CMM). Many research institutes have studied the temperature controlling environment for nanotechnology application [6].

Currently, most institutes have constructed expensive and spacious clean rooms to enclose all their equipments and operators. It results in difficult environmental control, high cost, and high energy consumption. In practice, only the micro/nano equipment is needed to be controlled at its specified location. This is the concept of "Mini Environment". For the need of precision micro/nano measurement, this research focuses on the active temperature control technology and proposes to develop a constant temperature environment chamber of high stability. The establishment of this mini environment chamber will not only help the development of mciro/nano measurement technology, but also benefit all other related mciro/nano researches, such as the processes of MEMS parts, laser lithography, optical communication parts, and CNT, etc.

The design of the environment chamber

The environment chamber is divided into three parts: the cooling chamber, the constant pressure chamber and the working chamber, as depicted in Fig. 1. The separation design of the working chamber from the cooling system aims to reduce the vibration caused by the thermoelectric cooling element. Air is cooled in the cooling chamber and then flow to the constant pressure chamber. The difference in pressure between the constant pressure chamber and the working chamber can keep the airflow steadily. The air finally flows back to the cooling chamber and recycles. The Pt-100 temperature sensor is fixed in the working chamber to send the feedback signals.

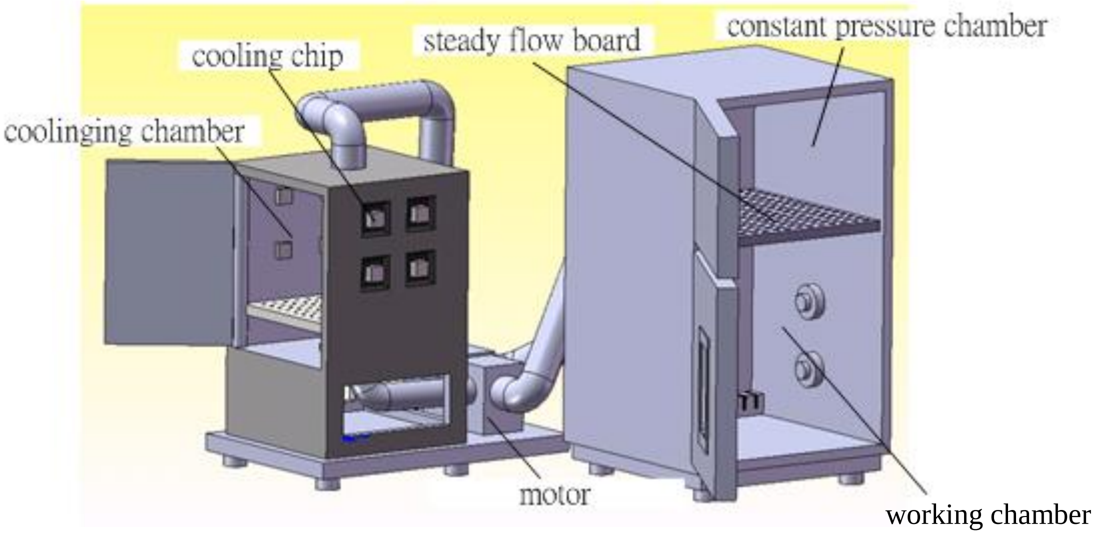


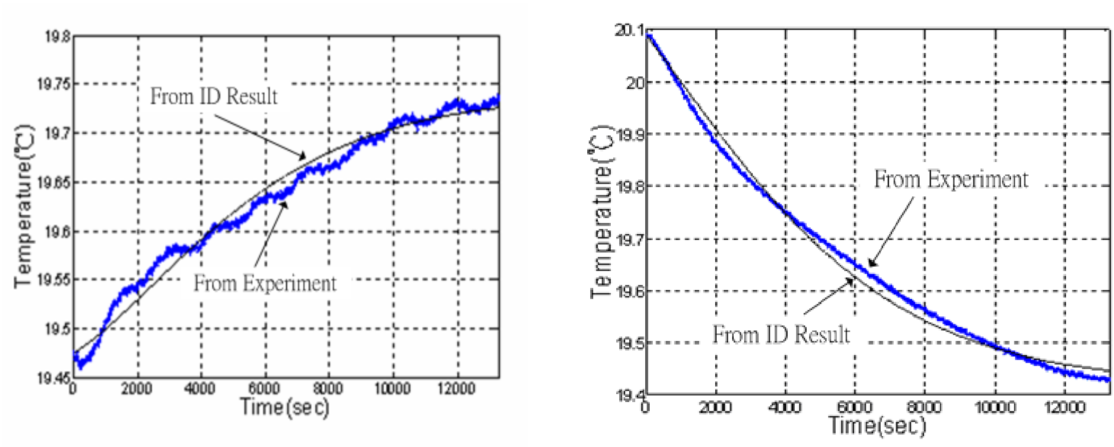
Fig. 1 The environment chamber layout

Experimental Set-up and Measurement Results

Control system design. We adopt the Rake's System Identification Method to calculate the open loop system transfer function. The input signal is the current that is generated to control the thermoelectric cooling chip, and the output signal is the temperature in the working chamber. The identification result shows that the open loop system transfer function $\tilde{G}(s)$ has two poles and one zero as Eq. (1). Fig. 2 shows the step response curve from the identification model $\tilde{G}(s)$ fitted to the experimental data.

$$\tilde{G}(s) = -\frac{-1.0542\times10^{-4}s - 9.3831\times10^{-8}}{s^2 + 5.204\times10^{-4}s + 8.5075\times10^{-8}} \quad (1)$$

In the closed loop control, using the Matlab Simulink software to simulate the proper PID controller parameters, the simulation result is shown in Fig. 3, where (K_p=20, K_i=0.0005, K_d=0) shows the best parameter set. Therefore, it can be used as the base tuning parameter. In real application, the PID controller parameters will be modulated according to the base tuning parameter to attain the best result.



(a) (b)

Fig. 2 Step responses from ID results and experiments (a) 1.5→0.5A; (b) 0.5→1.5A:

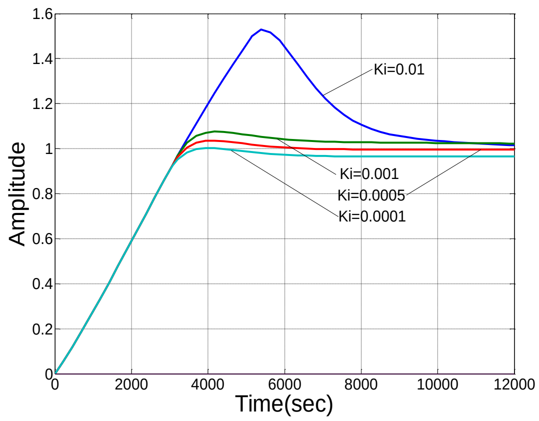
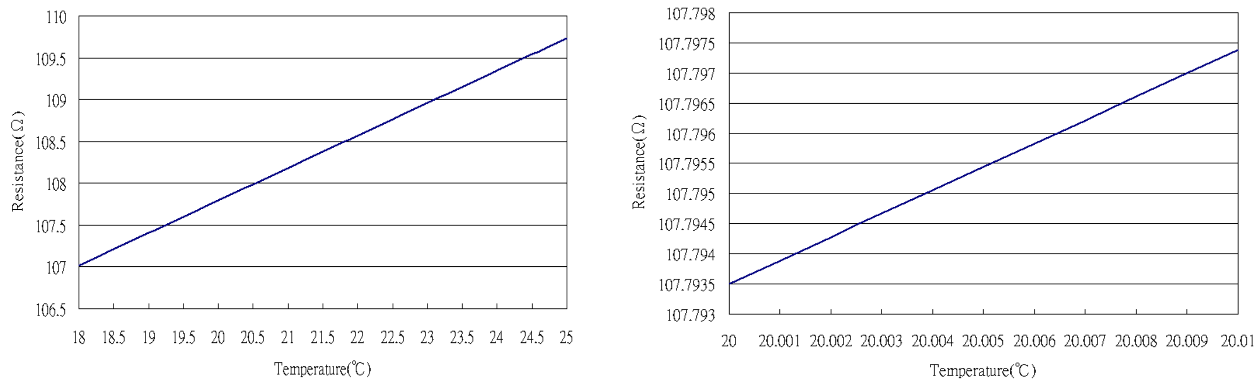


Fig. 3 Closed loop PID control simulation given K_p =20; K_i=0.0001~0.01; K_d=0

Temperature sensor calibration. The thermoelectric cooling chip is used as a cooling actuator in this research. It removes the heat load through the Peltier Effect [7]. The control system keeps temperature stability in the chamber by modulating the electric input current to the cooling chips. A Pt-100 temperature sensor is employed as the feedback signal [8-11]. This sensor is an A-class platinum thermistor which is calibrated by Callendar-Van Dusen equation shown as Eq. (2).

$$R(t) = R_0[1 + at + bt^2 + c(t - 100)t^3] \quad (2)$$

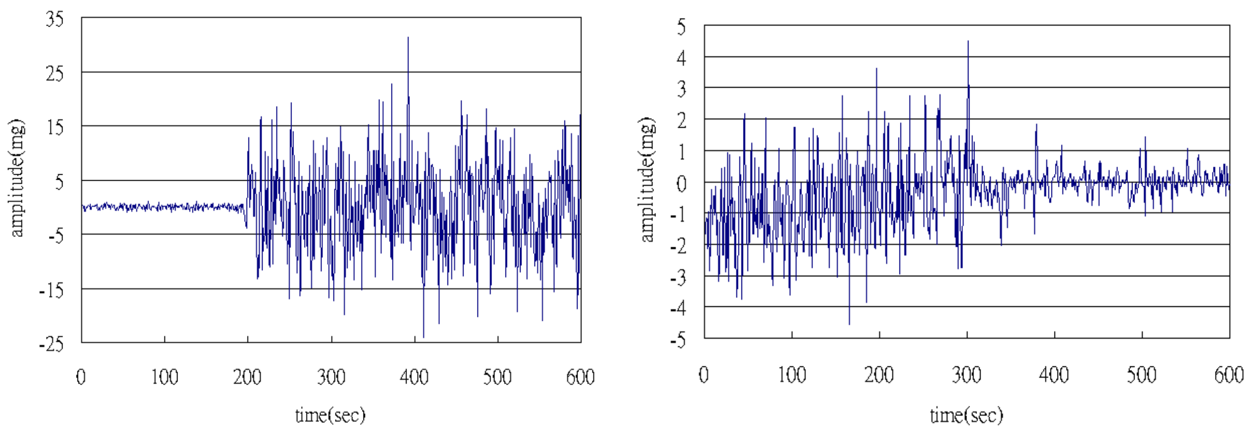
In Eq. (2), *t* is the temperature value, *R(t)* is the resistance of function *t and* R_0 the resistance value at 0°C, which is 100Ω. According to IEC 751 international standard, the resistance of the sensor is measured by the Agilent 34410A CMM 6½ Digital Multimeter. Coefficients in equation 2 can be obtained as a = 3.90830×10^{-3}, b = -5.77500×10^{-7}, c = -4.18301×10^{-12}. . The character curves are plotted in Fig. 4, with large range and small range separately.



(a) (b)

Fig. 4 Pt-100 sensor temperature character curve (a) 18~25°C ; (b) 20~20.01℃

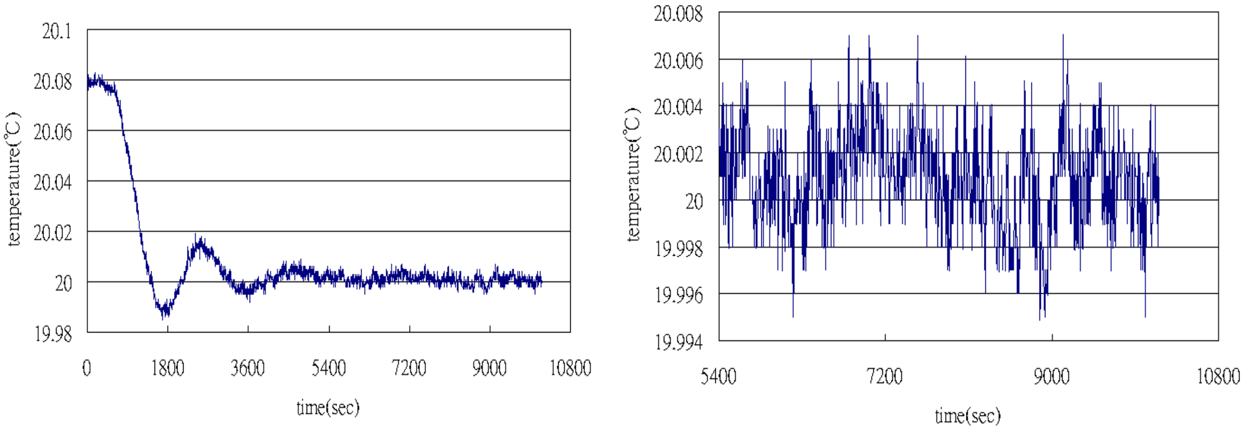
Vibration response measurement. In this research, the vibration of the working chamber and the cooling chamber are both measured. Fig. 5(a) shows the vibration of the temperature in the cooling chamber from inactivity to start. The amplitude change is about ±25mg. Fig. 5(b) shows the vibration of the temperature in the working chamber from start to inactivity, and the vibration amplitude is about ±4mg. The results show that the separation design can effectively reduce the vibration.



(a) (b)

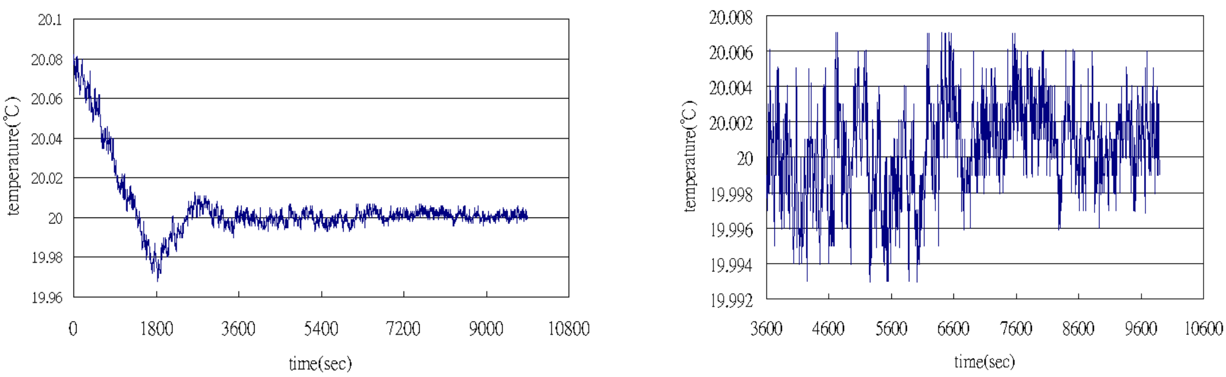
Fig. 5: The vibrations amplitude (a) in the cooling chamber (b) in the working chamber

Temperature response measurement. The environment chamber is tested in an air conditioned room. The temperature variation in the room is about 21±1°C. The PID controller parameter is modulated according to the base tuning parameter generated from simulation. As shown in Figs. 6 to 8, the temperature could be well controlled after an one-hour run at tuned PI parameters of Kp=20 Ki=0.0006. In the steady state, the temperature variation is within 20±0.007°C, as shown in Fig. 6(b), which indicates that the constant temperature environment chamber has a very high temperature stability. It has to be noted here that the Class I metrology room permits the temperature variation of 20±0.3°C in the room and 20±0.1°C in the vicinity of measurement location, as specified by ISO Guide 25-1982.



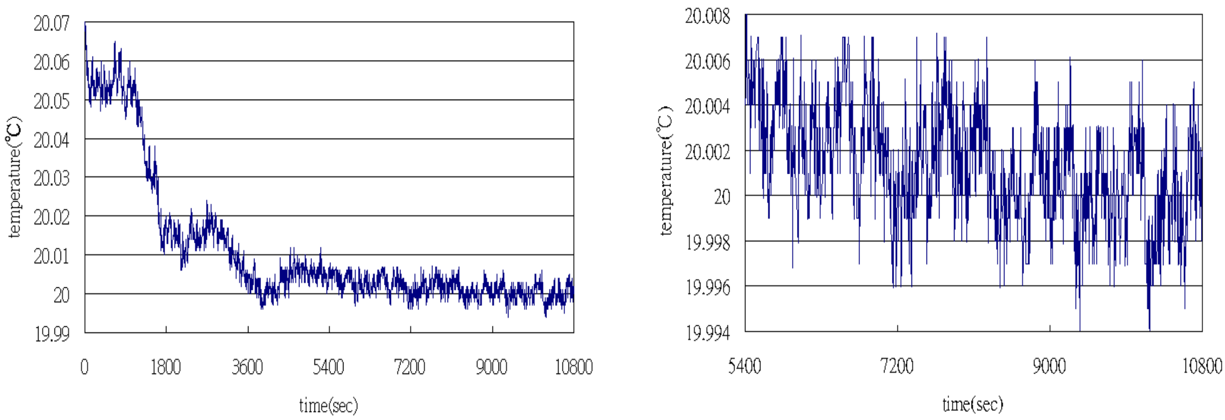
(a) (b)

Fig. 6 The control result (K_p=20, K_i=0.001)



(a) (b)

Fig. 7 The control result (K_p=20, K_i=0.0006)



(a) (b)

Fig. 8 The control result (K_p=20, K_i=0.0005)

Conclusions

In this study, a constant temperature environment chamber with high stability by separation design is proposed. In the proposed design, the outer temperature of the chamber is controlled by the air conditioner to the order of 21±1°C from which the inner temperature is controlled by the thermoelectric cooling chip. The separation design of the environment chamber for the cooling system can reduce the vibration caused by the thermoelectric cooling element. This system adopts the Rake's System Identification Method to obtain the system model, so that the optimum PID parameters can be acquired from simulation of Matlab Simulink. The results show that the temperature can be controlled within the temperature amplitude of 20±0.007°C in the steady state.

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