The 6th TSME International Conference on Mechanical Engineering
16-18 December 2015

TSF018

Accuracy Enhancement of Positioning Device by Feedback Cooling Based on Peltier Module

Takahiko Hakamata[1], Yutarou Teramoto[1], Jiro Ohtsuka[1], Takashi Nozaki[1], Atsushi Nakata[1], Ning Zhu[1*], Ryutaro Suzuki[2] and Tetsuhiro Nishide[2]

[1] Shizuoka Institute of Science and Technology, 2200-2 Toyosawa, Fukuroi,4378555, Japan
[2] THK.CO.,LTD(4-9-16 Higashikoujiya Ota-ku, Tokyo 144-0033, Japan
[*] Corresponding Author: zhuing@me.sist.ac.jp, Tel:+81-538-450232, Fax: :+81-538-450120

Abstract

Usually, for a positioning device based on semi-closed control method, positioning error caused by the thermal expansion of ball screw always occurs. It is understood that the ball screw nut and the two bearing supporting the ball screw with angular contact are contributing most to the thermal expansion. Hence, it is important that some cooling methods be used to keep the thermal expansion quantity unchanged. So far, the authors have suggested a unique cooling method where Peltier Module and PI control were employed, by which the thermal expansion is kept within 2.5μm when the stage speed is 150 mm/s. In this paper, in order to contain the thermal expansion within 1μm, PID control is applied to the current experimental system. According to experimental results, it is found that the thermal expansion tends to become stable after operation of 60 minutes. Even the speed of the stage is 150 mm/s, the thermal expansion quantity could be limited within1.0 μm if PID control feedback cooling at stage and housing were applied.

***Keywords**:* feedback cooling, positioning device, thermal expansion, Peltier module.

1. Introduction

There are several heat sources existing for the precision positioning device. During the operation, heat generated from the motor, the ball screw nut, stage guide and the electric circuit for driving and controlling the motor will increase the temperature of the ball screw, which leads to the thermal expansion.

So far, several methods have been suggested to deal with the thermal expansion in the precision positioning system. For example, a method of employing a hollow ball screw axis where the liquid coolant is flowed in and out to bring the extra heat out from the heated ball screw was proposed[1]. It was reported that the temperature of the cooling system could be controlled, however, the cost of introducing this kind of cooling system is very expensive. Besides, though there is a cooling method for cooling the ball screw nut, this method has not been widely utilized because the cost of introducing this system is so high too. In working machine, a method of applying the proper preload to the positioning system in advance by considering the expanded length caused by the thermal displacement drift was reported[2].

As for the method of cooling the whole precision positioning system, even the above-mentioned measures are suggested to prevent the ball screw from expanding, the heat generated from the motor will be transferred to the whole precision positioning system and the thermal expansion will not be decreased. In order to deal with this problem, a method where the whole apparatus is put inside an acrylic box to which the liquid coolant is introduced to control the temperature of the whole system has been suggested. However, this method is expensive and the precision system will be easily polluted by the liquid coolant.

Also, a method of employing Peltier module to cool a positioning system where ball screw was directly connected with a motor was proposed by the authors[3]. It was confirmed that with the introduction of the Peltier module, the heated positioning system could be cooled back to the room temperature and the thermal expansion was effectively decreased.

For a common positioning system, usually the motor is not directly connected to the ball screw, instead, a coupling is used to connect the motor with the ball screw.

This research aims at decreasing the thermal expansion by cooling the bearing as well as the stage based on Peltier effect for a one-axis precision positioning system where the axis of the motor and the ball screw are connected through a coupling system. As for the PID feedback control, especially the temperature feedback control system is applied to the housing and the gap sensor feedback control system is applied to the end surface of the ball screw. A precision positioning experiment system was established. temperature and thermal expansion measurement experiment were conducted. As a result, it was found that the total thermal expansion was within 1.0 μm.

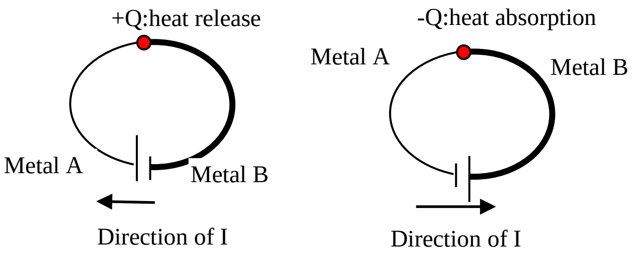

Fig.1 Peltier effect

2. Cooling Principle

Fig.1 shows Peltier effect. Assuming 2 different metals, say metal A and metal B, are connected. When a DC power is added to form a closed circuit and the electric current is flowed, it is observed that at the connected point heat release will occur respectively. If the electric direction is changed, heat absorption will occur. This is the famous Peltier effect, which was discovered by Peltier in 1834.

The absolute heat absorbed or released is expressed by

$$|Q| = \pi I \qquad (1)$$

Where π and I are Peltier coefficient and electric current, respectively. Actually, N-type and P-type transistors are used to assembly Peltier module instead of using metals.

When DC power is connected to the lead lines of the Peltier module, one side of it will become the cooling side (heat absorption) while the other side will become the heating side (heat release). When Peltier module is applied to a cooling system, a DC power is needed and the heat absorption side must be contacted tightly with the place to be cooled. Additionally, in order to effectively make full use of the cooling effect of the Peltier module, it is necessary to absorb the heat generated effectively by mounting a heat sink to the heat release side.

3. Experiment

A Thermal expansion control experimental system based on gap sensor feedback and temperature feedback shown in Fig.2 It consists of a precision positioning apparatus(THK CO.,LTD, KR45), a motor(AC 100 V, output 200 W), a bearing(DF), a coupling, 3 Peltier modules, DC powers and two feedback control systems.

For the precision positioning apparatus, the stoke of the stage that is amounted on the nut, the outer radius of the ball screw(SCM445) and the lead are 300mm, 15mm and 10mm, respectively. The material used for the bearing housing is cupper with higher heat conductivity. In order to cool the bearing efficiently from the bearing housing, the clearance between the bearing and the bearing housing is set to be about 20µm. Control instructions from a PC are transferred to the motor, then the stage will move forward and backward along the ball screw at different speed. Main material used for the apparatus is aluminum while it is S45C for the base, which is fixed to a steel plate by 4 bolts with the clearance of 10 mm in height.

In regard with the cooling system, places where the friction heat generates are to be cooled by the Peltier modules. Based on the preliminary experiment, it was found that the temperature increase in stage and the bearing during the stage movement were obvious, hence 3 Peltire modules(45mm×45mm) were amounted to the stage and the 2 sides of the bearing housing, respectively. In order to enhance the cooling effect, grease of high thermal conductivity is thinly pasted on all the contact surfaces. Also, a heat sink is mounted on the heat release side of the Peltier module where the heat absorbed is released by a motor fan as shown in Fig.3.

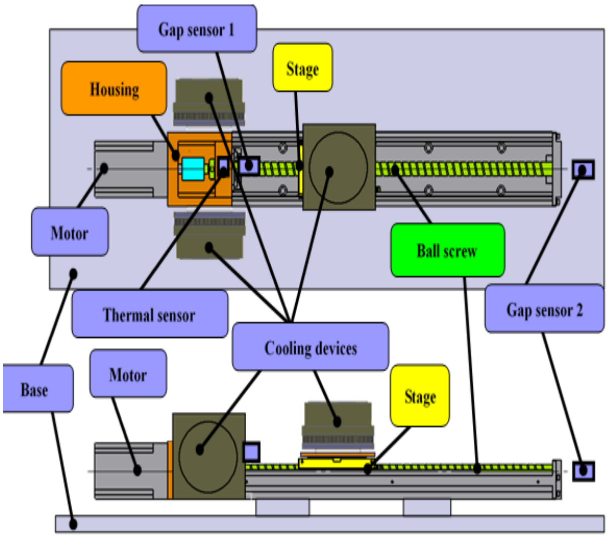

Fig.2 Thermal expansion control experimental system based on gap sensor feedback and temperature feedback.

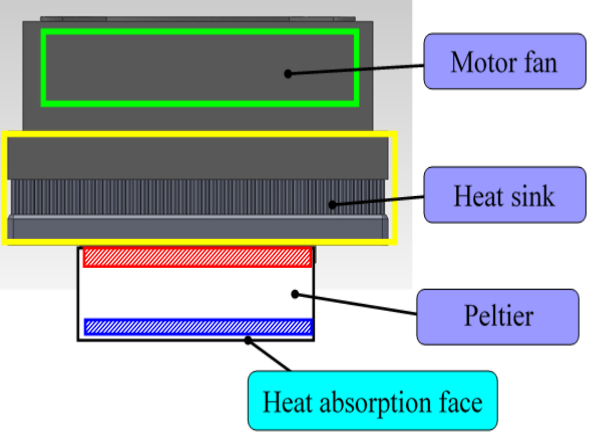

Fig.3 Structure of Peltier-based cooling unit

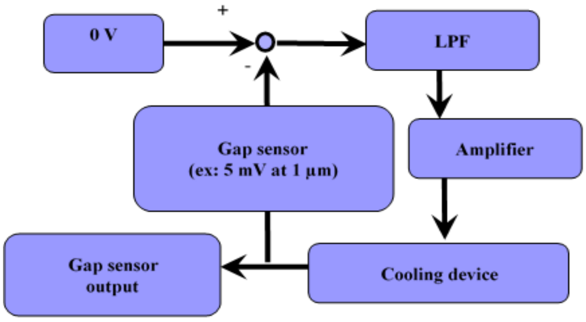

Fig.4 Flowchart of a gap sensor PID feedback control system

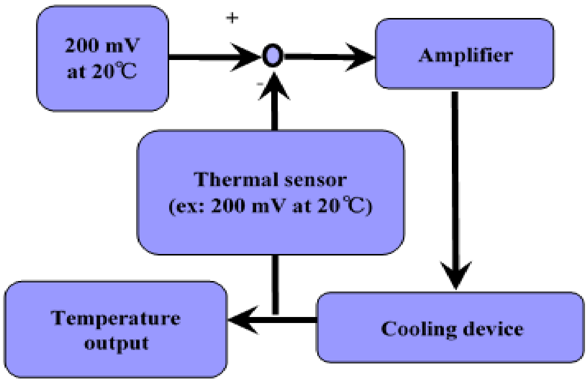

Fig.5 Flowchart of a temperature PID feedback control system

Two kind of feedback control systems are used for the thermal expansion control in this study.

As shown in Fig.4, gap sensor feedback control system consists of a gap sensor(Keyence, resolution:0.1µm), a controller and an amplifier. The gap sensor was set at the right side of the precision apparatus. When thermal expansion occurs, the distance(Total thermal expansion) Δl between the ball screw and the sensor will change. Then the signal from the gap sensor is collected by an interface circuit and converted to digital signal by an A/D converter. After some processing of PID control inside the micro-computer, the output signal is sent out through a D/A converter to the amplifier circuit to automatically adjust the voltage and the current supplied to the Peltier module.

As shown in Fig.5, temperature feedback system consists of a thermocouple, a controller and an amplifier. The difference value between the target temperature and the measured temperature vale obtained from the thermocouple which is located at the housing will be amplified by the amplifier. The output signal from the amplifier will be used to control the current that flows into the Peltier-based cooling unit. Besides, a set of K-type thermocouples are fixed to the upper part of the motor, the angular contact bearing that supports the ball screw(rotator) and the side of the guide to monitor the temperature changes of these places. Besides, the temperatures distribution along the axis line of the ball screw is measured at 50mm interval with a contact-type thermometer when stage stops.

The electric voltage applied to the Peltier module is also measured by a voltmeter.

Stage speed is set to be v=50,100,150mm/s, respectively with 1G, and the room temperature is kept 22±0.5 degree.

4. Results and Discussion

4.1 Temperature measurement and thermal expansion calculation

In Fig.6, the temperature distribution along the axis of the ball screw under the condition of with/without feedback control is shown. Before operation, the temperature of the ball screw appeared to be unchanged. After the stage of the positioning device moved forward-and-back at v=150mm/s with ±1G without Peltier-based cooling for 30min, the temperature of the bearing housing, defined as the start point, reached 22.6 degree while the surface temperature in the middle of the ball screw was up to 24 degree. After feedback cooling was conducted, the temperature profile tended to be the one obtained before operation except the change near the starting point.

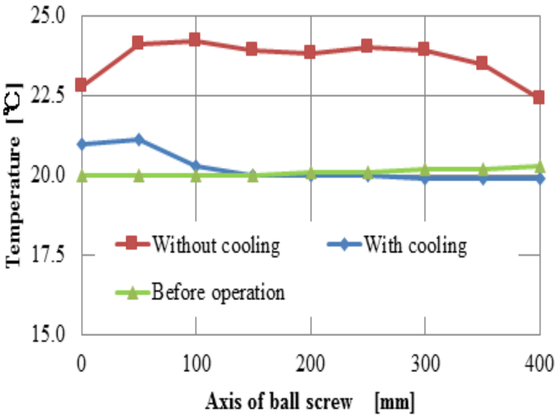

Fig.6 Temperature distribution along the ball screw

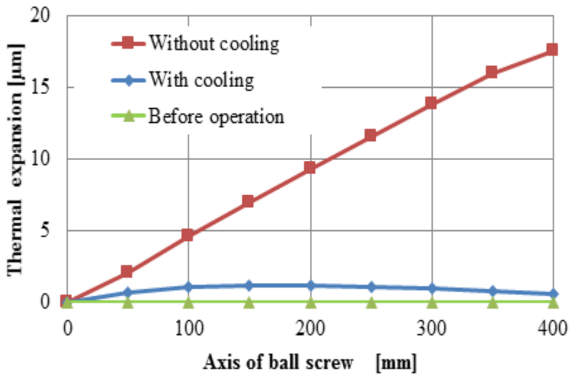

Fig.7 Calculated thermal expansion quantity

Based on the temperature value obtained, the thermal expansion Δl is calculated by using Eq.2

$$\Delta l = a \Delta T L \tag{2}$$

where a, ΔT and L are linear expansion coefficient, temperature difference and length, respectively.

The calculated results are shown in Fig.7. Before operation, it is found that there is no thermal expansion. However, the total thermal expansion of the ball screw reached 18μm in case of without cooling while it became around 2.5μm in case of cooling. This demonstrated that without proper control, it would be very difficult to keep the thermal expansion under control.

4.2 Thermal expansion measurement with PID feedback control

Fig.9 shows the temperature changes in the bearing housing at stage speed of 50, 100 and 150 mm/s, respectively. When PID control was used. It was found that the range of temperature change is limited compared with the experimental data obtained from P feedback control.

Fig.10 shows the thermal expansion at the axial end surface when PID feedback control was applied to temperature. The displacement quantity of the edge axial could be decreased within 1μm at the stage speed of 50 mm/s, 100mm/s, 150mm/s, acceleration of ±1G.

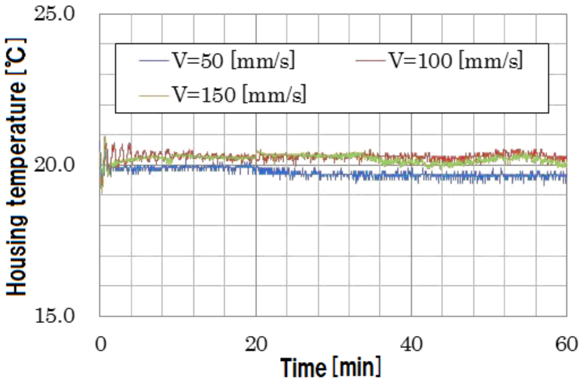

Fig.9 Housing temperature by PID control

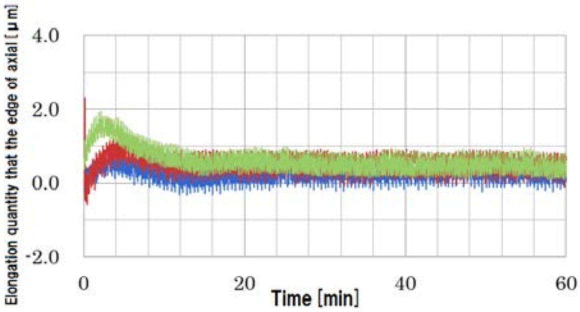

Fig.10 Thermal expansion at axial end surface

5. Conclusion

PID feedback control method was applied to positioning device cooling based Peltier module. A positioning device system where a ball screw was employed was established to verify the feasibility of the method suggested above. Based on a serial of experiments and calculation, some conclusions were obtained as follows:

(1) At v=150mm/s with ±1G without Peltier-based cooling for 30 min, the thermal expansion was 16μm;

(2) After the gap sensor signal feedback control as well as temperature feedback control based on PID were conducted, the total thermal expansion was limited to 1.0μm, which demonstrated the effectiveness of the double PID feedback method proposed.

6. Acknowledgement

This research is supported by Grants-in-Aid for Science Research[(C) 560123] from Ministry of Education, Culture, Sports, Science and Technology, Japan.

7. References

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