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Temperature Control of Industrial Water Cooler using Hot-gas Bypass

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***Abstract*—**In this study, we experiment on precise control outlet temperature of water from the water cooler with hot-gas bypass method based on PI control logic for machine tool. Recently, technical trend for machine tools is focused on enhancement of speed and accuracy. High speedy processing causes thermal and structural deformation of objects from the machine tools. Water cooler has to be applied to machine tools to reduce the thermal negative influence with accurate temperature controlling system. The goal of this study is to minimize temperature error in steady state. In addition, control period of an electronic expansion valve were considered to increment of lifetime of the machine tools and quality of product with a water cooler.

***Keywords*—**Hot-gas bypass, Water cooler, PI control, Electronic Expansion Valve, Gain tuning

I. INTRODUCTION

RECENTLY, various researches and developments about oil and water cooler for cooling a machining parts of machine tools are being proceeded. Processing part of machine tools generates heat because cutting speed is so fast. Machining parts and products are transformed caused by this heat and then these deformation bring about lower accuracy of processing and reliance of machine tool.[1][2] Therefore, oil and water coolers are applied to prevent generation of heat. Existing On-Off control type can't control temperature accurately because compressor is operated and stopped repeatedly and causes increment of power consumption and decrement of the expected life of compressor. There are two kinds of more accurate temperature control types than On-off control type. The first type is control with bypass of exhausting gas, the other type is control mass flow rate with control the number of rotation of compressor.[3]

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In this study, accurate temperature control system is designed and analyzed using first type. This system controls temperature with control of opening step of EEV (Electric Expansion Valve) which is bypass valve of exhausting gas using PI (Proportional Integral) logic. PID gain which is important factor on temperature control is the core of design in this research. Therefore, PID factor is found with various tuning method of gain, and PID gain is set using method of Ziegler-Nichols, and then performance of this system is analyzed through the experiment.

II. CONTROL OF AN WATER COOLER WITH HOT-GAS BYPASS

A. System of an water cooler

Fig. 1 shows the schematic diagram of a water cooler. Cooled water from water cooler is supplied to the machine tool to remove the thermal load of machining parts. The water absorbs heat and gets back to tank, and then flows into a water cooler through the pump. Therefore, outlet water temperature from water cooler is retained constantly to prevent thermal deformation.

B. Manner of hot-gas bypass

There are three kinds of hot-gas bypass type. The first type,

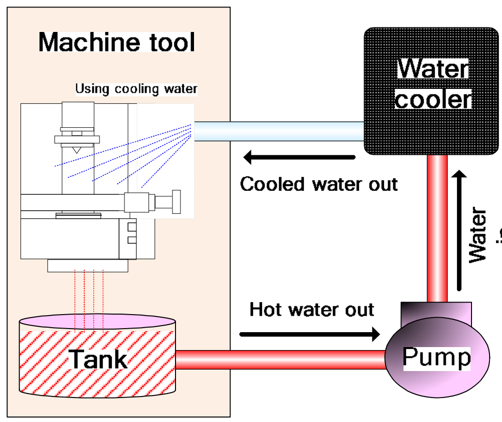


Fig. 1 Schematic diagram of a water cooler

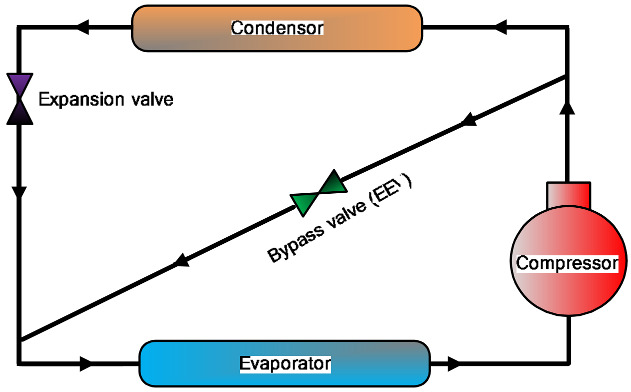


Fig. 2 Schematic diagram of hot-gas bypass system

the refrigerant which comes from the outlet of compressor is send to the inlet of evaporator. The second type, the refrigerant which comes from the outlet of compressor is send to the outlet evaporator. The last type, the refrigerant which comes from the outlet of compressor and that of outlet of condenser are mixed together and then they are sent to the outlet of evaporator.

In the first type, the temperature of refrigerant from the outlet of compressor will be lower, so it can be operated safely. Also, the range of control is wide because range of cooling capacity change is largest in the three kinds of types. So this method is applied to this study. [4][5]

Fig. 2 shows schematic diagram of hot-gas bypass system. In this fig., the refrigerant which comes from the outlet of compressor has high-temperature and high-pressure detour to the inlet of evaporator, and then it will be mixed with the low-temperature and low-pressure refrigerant. For this condition the cooling capacity will be lower.

Therefore, outlet temperature of water cooler is constantly maintained by control opening of EEV which is hot-gas bypass valve.

C. *Design of a PID controller*

The temperature error is found by using this equation, $e = T^* - T$, and the PID controller generates input value of control, so that it becomes 0, and then sends it to a driver. The PID controller decides output, u(t), through proportional – integral equation as shown in the equation (1). The design of the PI controller is a process that decides K_P, K_I, K_D to satisfy to given specification of design.

$$u(t) = K_P e(t) + K_I \int_0^t (t)dt + K_D \frac{d}{dt} e(t) \qquad (1)$$

Fig. 3 is a block diagram of a PID controller to control the outlet temperature of a water cooler. There are two kinds of design method. The first method is based on mathematical modeling, and the other is gain tuning method is not based on mathematical modeling.

The water cooler consists of a compressor, an expansion device and a heat exchanger. In fact, since all such components in the cycle are connected with various pipes and valves, so they show nonlinear characteristics in operation.

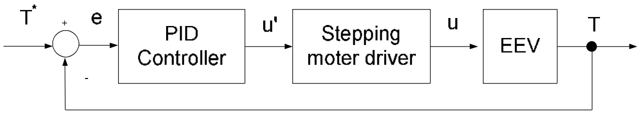


Fig. 3 Block diagram for EEV control

According to this reason, it is impossible to identify dynamic characteristics and to get applicative mathematical model exactly. Therefore, method of PID control which is using method critical oscillation is applied.

In this research, control period is set 1 second and 10 seconds respectively. It decides gains by the critical oscillation method, and then is confirmed its performance of control through an experiment.

D control can prevent the disturbance quickly, but influence on the sampling period. Therefore, only PI control is applied to design specifications.

III. EXPERIMENT

Fig. 4 and Fig. 5 show schematic diagram of control system of a water cooler for a machine tool and experimental apparatus, Table 1 and Table 2 show specification of the experimental apparatus and experimental conditions.

The water cooler is composed by an evaporator, a compressor, a condenser, a capillary tube and EEV. The control device is composed by a PLC (Programmable Logic Controller) and a stepping motor driver. Also, the temperature of water outlet is measured with the PT-100 which converted temperature into voltage through a converter, and then transmitted to the PLC. The temperature of water outlet and the setting temperature transmitted from the PLC were compared with each other, and

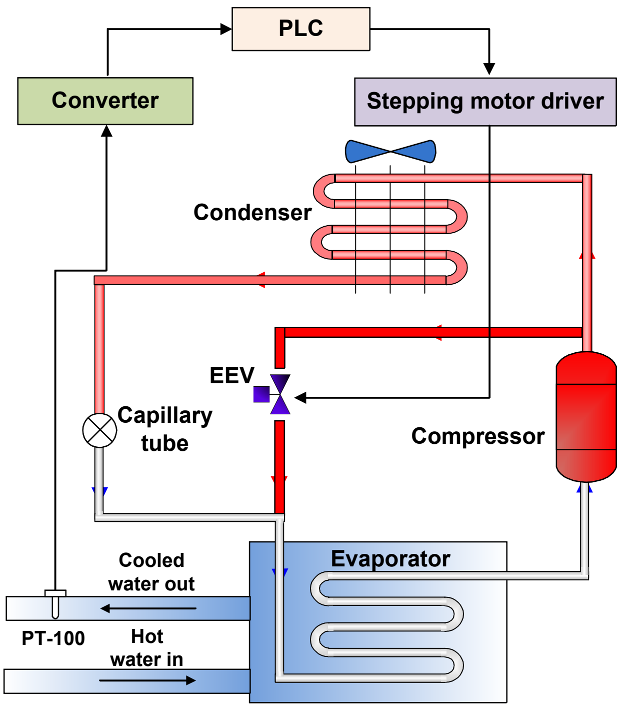


Fig. 4 schematic diagram of control system of a water cooler

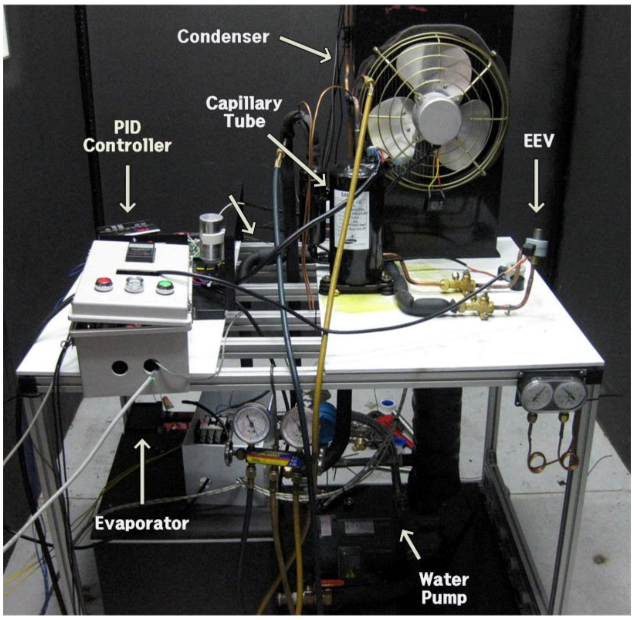


Fig. 5 Experimental apparatus

TABLE I
SPECIFICATIONS OF EXPERIMENTAL APPARATUS

Compressor	Rotary type,1HP
Condenser	Air-cooled fin and tube type
Evaporator	Coiled tube type
Refrigerant	R-22

TABLE II
EXPERIMENTAL CONDITIONS

Mass flow rate of water	25	[L/min]
Air temperature	35	[ ]
Control period	1 or 10	[sec]

then the value is send to stepping motor driver, so that its error becomes 0 by a PI controller. The stepping motor driver makes a value as pulse, and then controls an opening of EEV.

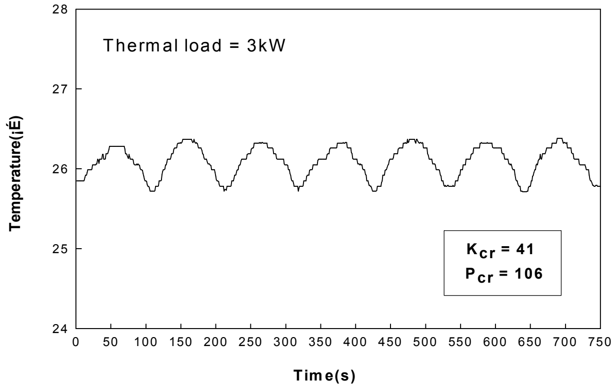
In order to understand the operation process of a water cooler, the temperature of a main part is measured by T-type thermocouple. Data such as temperature, electric power, valve opening and water flow rate are measured through a collecting device (MX-100, Yokogawa).

IV. RESULTS AND CONSIDERATIONS

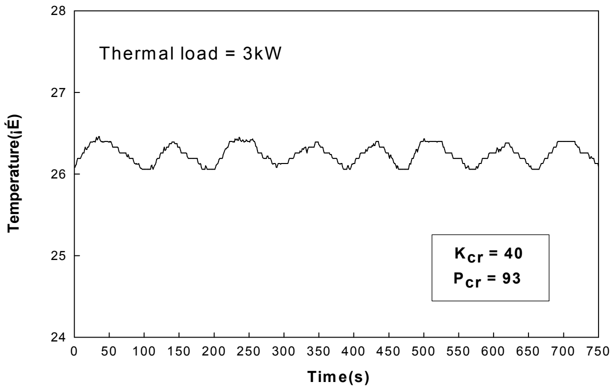
In this study, outlet temperature of water cooler is assumed 25. considering characteristic of industrial machine, and it is fixed to supply constant temperature of water to machine tool. Controller is required to maintain outlet water temperature of water cooler within errors, even if disturbance occurs.

Fig. 6 shows critical oscillation responses by changing a control period, 1 second (Case 1) and 10 second (Case 2) in 3kW load respectively. K_{cr}(Critical gain) and P_{cr}(Critical period) are obtained for gain tuning. Then K_p and K_i are calculated using before obtained values through equation (2).

$$K_p = 0.45 K_{cr}, \quad K_i = \frac{0.54 K_{cr}}{P_{cr}} \tag{2}$$

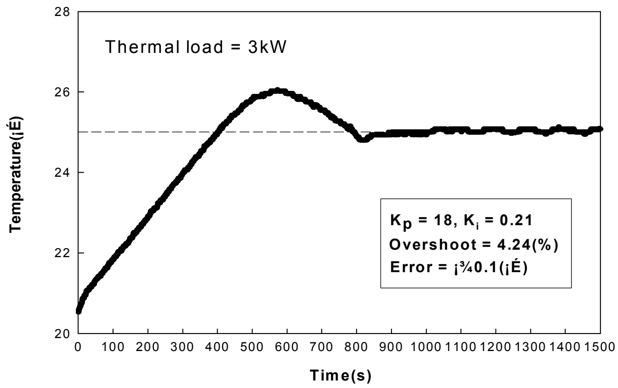


(a) 1 Second period

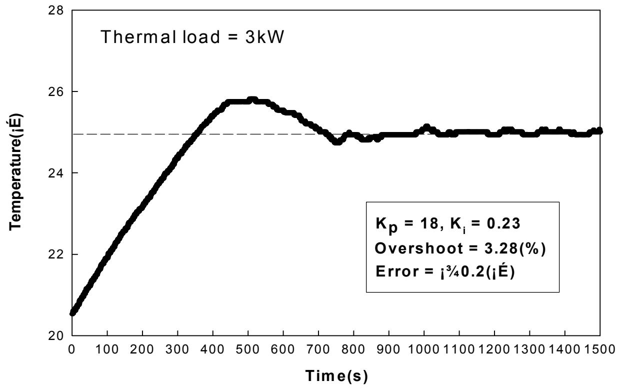


(b) 10 Second period

Fig. 6 Critical oscillation responses



(a) 1 Second period



(b) 10 Second period

Fig. 7 Results of control performance with PI

Fig. 7 shows results of PI control using value of gains which are obtained from equation (2) in a 3kW load and compared with case 1 and case 2. Performance of temperature control of case 2 is shown within 0.1% error and that of case 2 is shown within 0.2% error. Values of overshoot are shown 4.24% and 3.28% in case 1 and case 2, and that of case 1 is 0.96% higher than that of case 2. In the result, both of performance of two case are satisfied within 0.2% error.

TABLE III
PID GAIN ACCORDING TO TUNING METHOD

Control Period	Controller	Over shoot (%)	Error ( )
1 Second(Case 1)	PI	4.24	0.2
10 Second(Case 2)	PI	3.28	0.2

Fig. 8 and Fig. 9 show performances of two cases under changing of disturbance. Temperature of water cooler outlet is maintained temperature 25% even if disturbance is changed, and after settled steady state, error of temperature is maintained with in ±0.2% in the both cases. In the opening step of EEV, case 2 shows larger opening step mainly than that of case 2. Also, oscillation range of opening step of case 1 show larger

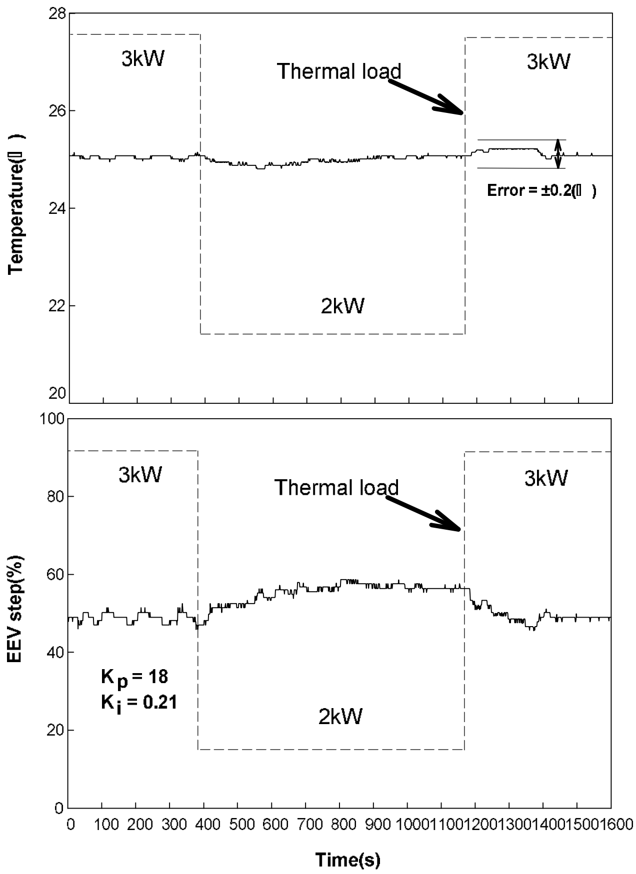


Fig. 8 PI control response under variation of disturbance at 1 second period

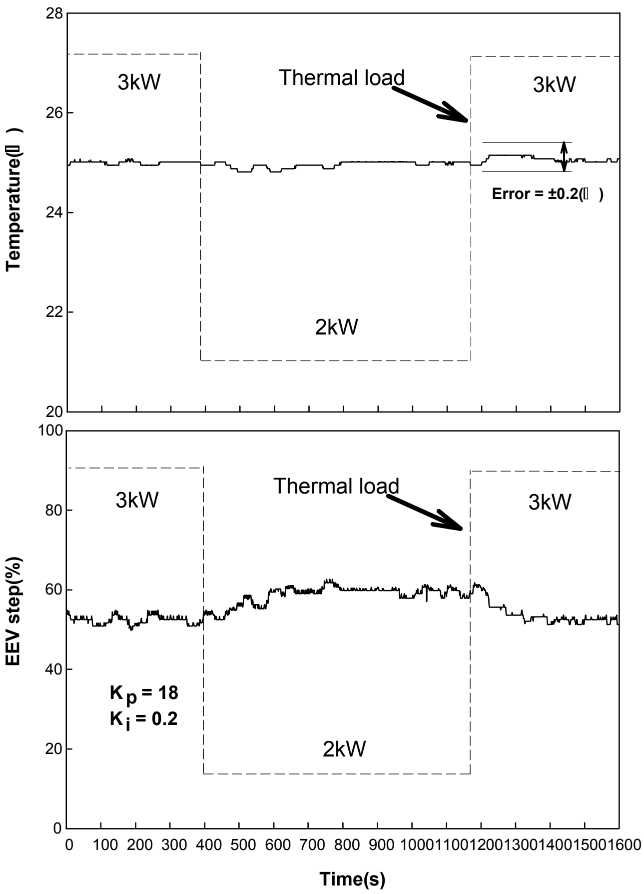


Fig. 9 PI control response under variation of disturbance at 10 second period

than that of case 2 under changing of disturbance. These results are caused by control period which has influence on accuracy of control. As a result, both cases are show satisfied performance to maintain outlet temperature of water cooler.

V. CONCLUSION

In this study, PI controller is designed using type of hot-gas bypass for precise control of temperature. Gain of PI is decided easily by method of critical oscillation response, excellent performance of control is shown with 3.28% overshoot and ±0.2% error of steady state. Also, error range of temperature is controlled within 0.2% although disturbance occurs.

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