PUM Multi-loop Modular Temperature Controller

Hideyuki Konishi
Jun Ando
Fukiko Kawai

1. Introduction

The miniaturization of semiconductors and advances in flat panel display (FPD) technology are examples of factors that have enabled the dramatic development of digital devices in recent years. It is imperative that the temperature control used in manufacturing processes for these state-of-the-art devices is highly accurate, upwardly scalable (supports multiple zones) and enables shorter tact times in order to improve the manufacturing efficiency. Moreover, accurate multiple zone-based temperature control is also required for other equipment, such as reflow soldering machines and plastic molding machines, also used in the manufacturing processes for electronic devices in order to realize higher quality and to save energy.

On the other hand, as a result of the trend toward the miniaturization of equipment, the controllers incorporated into such machines are being made smaller year after year. Consequently, the wiring work has become more difficult and there is an ongoing tendency to omit accessories (such as an indicator lamp) not directly related to functionality.

Under these circumstances, Fuji Electric has developed the PUM multi-loop modular temperature controller with the following three objectives.

(a) To support requests for smaller size controllers in equipment while improving the ease of use of those controllers
(b) To realize improved control performance in a control system where interference exists between loops, which is difficult to resolve with a single temperature controller
(c) To satisfy our customers in the multi-loop temperature control market

2. Overview of the PUM Multi-loop Modular Temperature Controller

Figure 1 shows the external appearance of the PUM. Six modules are connected in this figure. The modules are directly connected together by connectors mounted on the left and right sides of each module, and this structure does not require any sort of baseboard. The connectors connect an internal bus and also the power supply and an external RS-485 channel, thereby eliminating the need for individual wiring to each module. Moreover, because an internal bus links data among the modules, computations and coordinated operations can be performed amongst the control loops. On the other hand, there are no common components such as a CPU module or power supply model inside the system, and each module can also operate individually.

Fig.1 External appearance of PUM multi-loop modular temperature controller

3. Specifications of the PUM Multi-loop Modular Temperature Controller

The types of modules and their specifications are listed in Table 1, and an example system configuration is shown in Fig. 2.

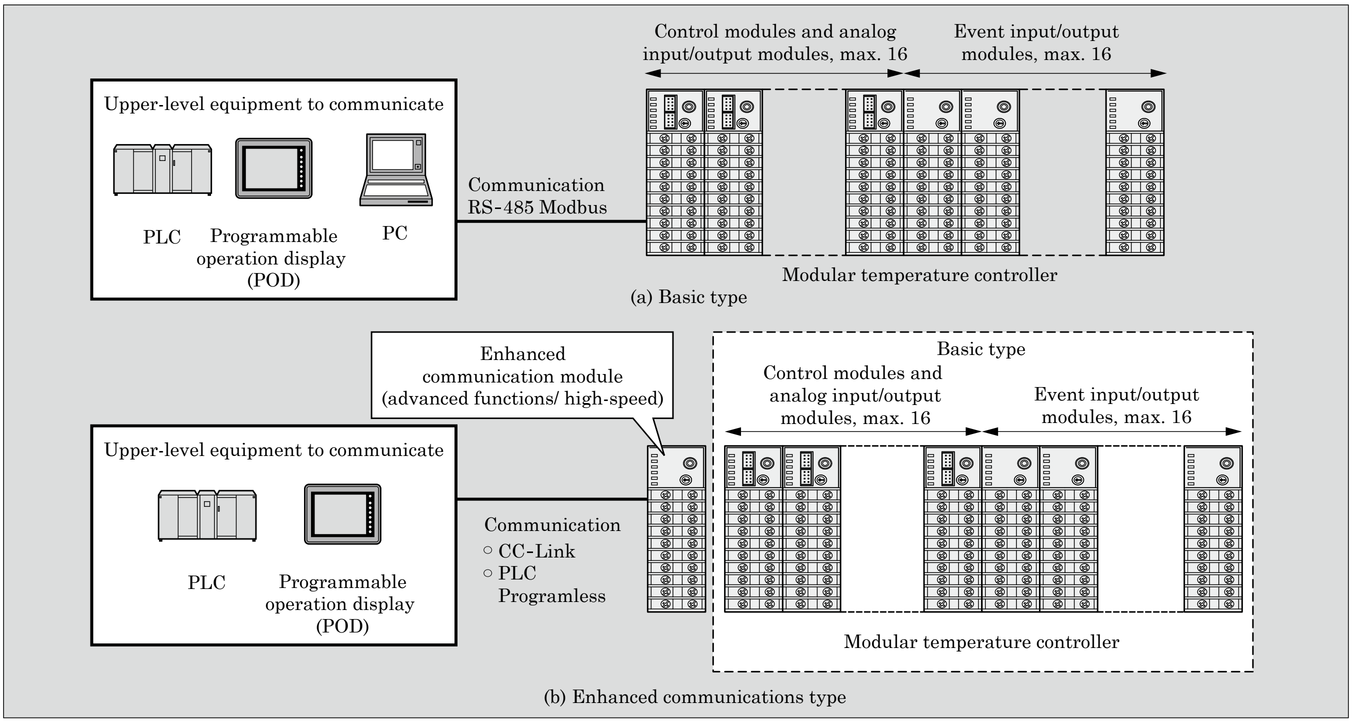
The modules can be broadly classified into the three categories of analog series modules, digital series modules and enhanced communication modules. The analog series modules include a 4-channel control module, 2-channel control module, analog input/output module, analog input module, and an analog output module. The digital series modules include an event input/output module.

A single connected system can contain a maximum of 16 analog series modules, 16 digital series modules, and one enhanced communication module. Accordingly, a maximum of 64 loops, with 128 points of digital

Table 1 Module types and specifications

Module	Specification item	Specification	Max. number per system
Common specifications of each module	External dimensions Communication function Parameter loader communication port Input accuracy Input sampling cycle Power supply	30 (W) × 85 (D) × 100 (H) (mm) RS-485, Modbus RTU, 115.2 kbits/s max. RS-232C ±0.3% 200 ms 24 VDC ±10 %	—
Control module Model : PUMA/B	No. of control channels Input type Control function Output type Heater break detector (CT) input	4-channel (PUMA), 2-channel (PUMB) Thermocouple/ resistance-temperature detector, voltage/ current PID control, PID heat/cool control Relay contact output, SSR driver output, current output 4 to 20 mADC 8 points	16 modules in total
Analog input/output module Model : PUMV	Input points/ output points Input type Output type	4 points/ 4 points Thermocouple/ resistance-temperature detector, voltage/ current Current output 4 to 20 mA DC	
Analog input module Model: PUMN	Input points Input type	4 points Thermocouple/ resistance-temperature detector, voltage/ current	
Analog output module Model : PUMT	Output points Output type	4 points Current output 4 to 20 mA DC	
Event input/output module Model : PUME	Input points/ output points Input type Output type	8 points (4 points/ common × 2 blocks)/ 8 points (4 points/ common × 2 blocks) Voltage contact input, common for sink/source (bi-directional) Relay output, transistor open collector (sink output)	16 modules
Enhanced communication module Model : PUMC	Communication standard Communication speed Communication function	RS-422/RS-232C/CC-LINK RS-422, RS-232C: 230.4 kbits/s max. CC-LINK: 10 Mbits/s max. CC-Link, PLC programless communication	1 module

Fig.2 System configuration example



input and output, can be controlled. The analog series modules and the digital series modules are equipped with high-speed communications functions (RS-485, Modbus*1 RTU protocol, maximum communication

*1: Modbus is a registered trademark of Gould Modicon, Inc.

speed of 115.2 kbits/s) as standard, and do not require the addition of a separate communications module. Moreover, communication using CC-Link, PLC programless communication or additional protocol other than Modbus RTU can be supported with the enhanced communication module.

4. Technical Challenges and Details of Efforts

4.1 Simultaneous realization of smaller size and improved ease of use

(1) The realized module size of 30 (W) × 85 (D) × 100 (H) (mm), which is the industry's smallest class, and 3-block detachable structure consisting of a terminal block, main unit block and base block as shown in Fig. 3 make it possible to wire only the terminal block when installing new wiring offsite, or if replacing a module after onsite delivery, to swap out the main unit block without having to change the wiring and the installed state. Moreover, indicator lamps for all input and output signals are installed, so that the operating condition may be confirmed from the main unit block itself.

(2) A parameter loader communication port is located on the front of each module, and parameter loader software can be used to set, control and monitor the main unit. In addition to the method of connecting each module individually, a master module connection function is also provided and enables the entire system to be connected with only a single connection to the module set as the master in the system (see Fig. 4). This function realizes both simplicity and excellent maintainability.

Fig.3 3-block detachable construction

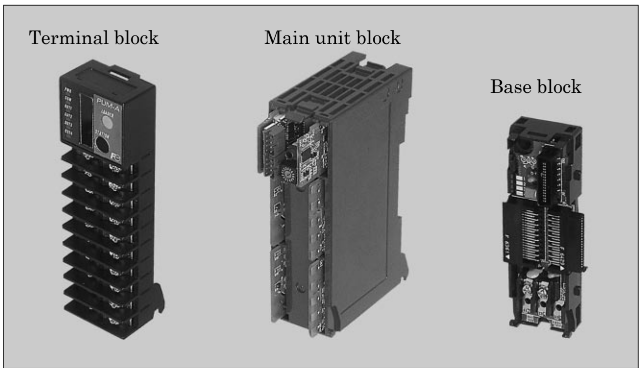
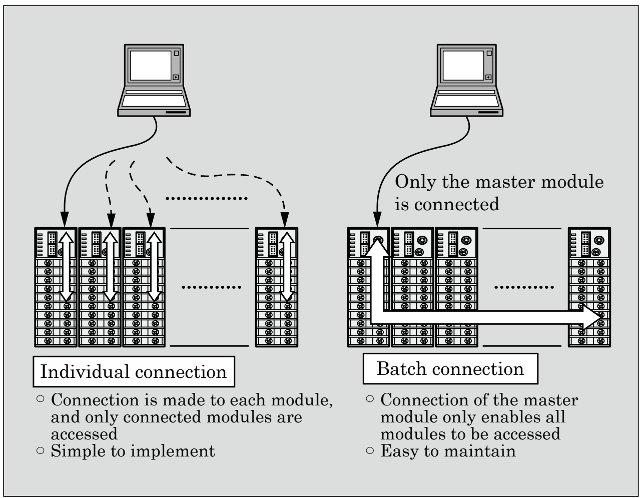


Fig.4 Parameter loader port connection method



Moreover, the parameter loader software is equipped with a "favorites" registration function that allows the user to register commonly used parameters (see Fig. 5) and contributes to the improved ease of use.

4.2 Improved control between control loops

Multi-zone optimal control technology using model predictive control reduces thermal interference from adjacent zones, and thus enables more precise control. An application example is described below in Section 5.

4.3 Increased customer satisfaction in the multi-loop temperature control market

(1) Improved communication performance

In the past, when a system became large in size, the speed of data updates via a communication path decreased, and consequently, the operational feel when updating data from an operation display or the like was mostly lost.

This slowdown is due to the following two factors.

(a) Communications speed is insufficient for the quantity of data

(b) Due to the increasing number of transmissions, the transmission frame header, response time, and the like, are appended to each transmission, and the time required to transmit other parameters besides communications data can no longer be neglected

The PUM has adopted measures to counteract each of these factors.

As a measure to improve the communications speed, the speed has been increased to 115.2 kbits/s, by a factor of 6, from the previous speed of 19.2 kbits/s for previous products.

The reason for the increased number of transmissions is because the parameters (addresses of communications data) to be accessed from the host are

Fig.5 Parameter loader software "favorites" registration function

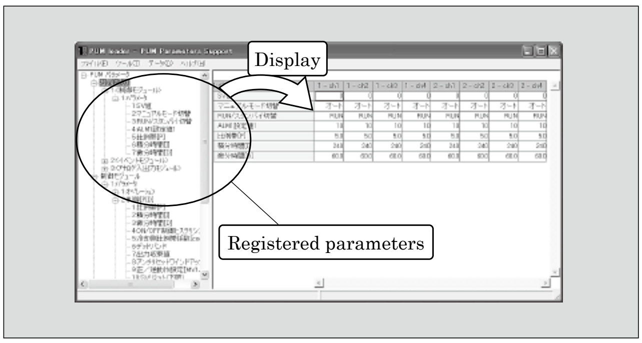
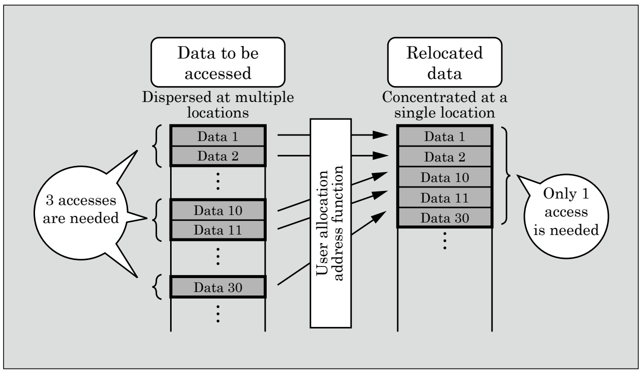


Fig.6 User allocation address function



non-sequential. Therefore, the PUM is provided with a "user allocation address" registration function that relocates data stored at non-sequential addresses to a continuous series of addresses, so transmissions to the same station can be collectively performed in a single access (see Fig. 6). Moreover, by using the enhanced communication module, all connected modules can be treated as a single station. The collection of data previously required the same number of transmissions as there were modules, but with the PUM, the number of transmissions can be reduced to one.

(2) Removal of restriction on number of control points when adding functions

A 4-channel control module is provided with heater break detector CT (current transformer) inputs at 8 points. Accordingly, 3-phase power break detection is possible for each channel without reducing the number of control loops. In Fuji Electric's previous products, the CT input was limited to a single-phase CT input, and a 3-phase detector had to be installed separately when 3-phase detection was required. As a result, regardless of whether a 3-phase heater break detection function is provided, the same minimal system configuration (number of control modules, input and output wiring) can be used as needed, helping to reduce construction cost for a customer system.

5. Example Application of Multi-zone Optimal Control

In a multi-zone temperature control system, one cause of decreased temperature stability is thermal interference from an adjacent zone, and by decreasing this thermal interference, improves the temperature stability. With the conventional method of PID control, the decrease in thermal interference was limited because of the single loop control. Therefore, multi-zone optimal control using model predictive control, for which the results of many successful applications to oil and chemical plants have been reported[(1)(2)], was developed and applied to injection molding machines to verify its effectiveness.

In model predictive control, the algorithm has a model (internal model) of the object to be controlled,

Fig.7 Conceptual diagram of model predictive control

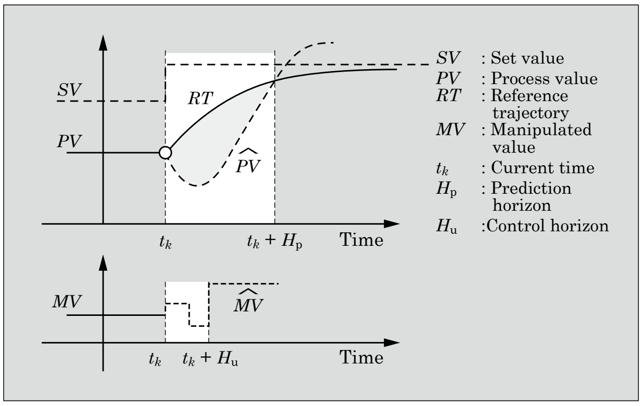
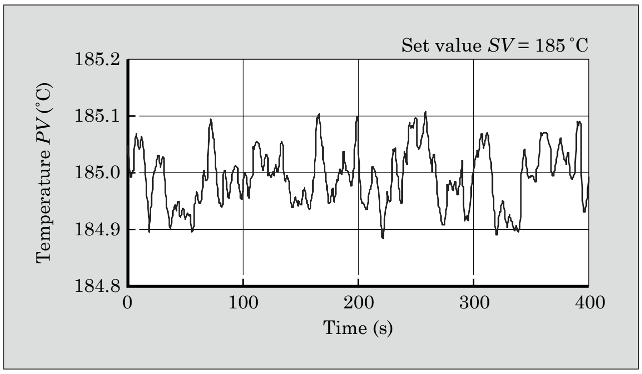


Fig.8 Temperature stability of nozzle with conventional control method (PID control) only

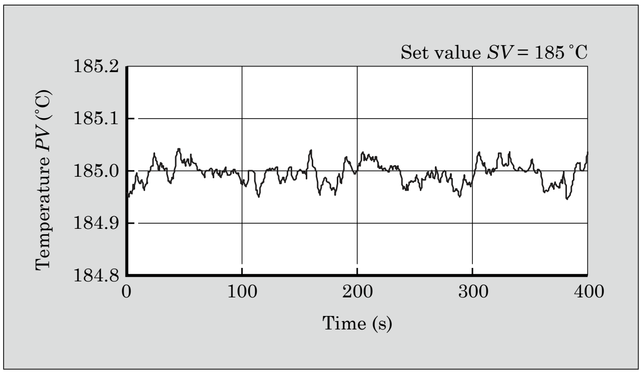


and a value for the amount of manipulation is determined such that the behavior of the object to be controlled is optimal from the present time until a certain future time. Figure 7 shows a conceptual diagram of model predictive control.

Consider the case in which a set value SV is changed at the current time t_k. A future manipulated value MV is calculated such that the difference between a preset reference trajectory RT and a future process value PV calculated from the internal model is a minimum during the interval known as the prediction horizon H_p. At this time, the manipulated value MV is assumed to operate only during an interval known as the control horizon H_u. Of the subsequently calculated manipulated values MV, the manipulated value MV (t_{k+1}) at the time t_{k+1} is the actual manipulated value. Repeating this operation sequentially enables optimal control to be implemented constantly while predicting the future. The above-described advantage is easily extended to cases where there is a multivariable system (interference system) or limitations on the object to be controlled.

We applied multi-zone optimal control to an actual injection molding machine (80 ton, 4 zones). Figure 8 shows the temperature stability of the nozzle (width: 0.2 °C, ±0.1 °C) when using a conventional control method (PID control) only, and Fig. 9 shows the nozzle temperature stability results (width: 0.1 °C, ± 0.05 °C)

Fig.9 Temperature stability of nozzle with multi-zone optimal control



when using multi-zone optimal control. From these results, we verified that the temperature stability was improved due to the multi-zone optimal control.

6. Postscript

With the higher level of quality requested of manufacturing technology, manufacturing equipment is trending toward more dense and sophisticated designs, and Fuji Electric has developed the optimal controller for incorporation into such manufacturing equipment. Multi-zone optimal control technology has realized stable temperature control in adjacent injection molding machines.

In the future, to widen the range of applications, we plan to apply multi-zone optimal control to the FPD industry for temperature control in semiconductor manufacturing equipment. Moreover, by improving the present specifications for the input sampling cycle (200 ms) and input accuracy (± 0.3% FS), and by supporting various types of communication functions, Fuji Electric intends to develop modular controllers applicable to various diverse industries.

References

(1) S. J. Qin, et. al. "A Survey of Industrial Model Predictive Control Technology," Control Engineering Practice, vol. 11, 2003, p. 733-764.

(2) IEEE Control Systems Magazine, Snapshots of Process Control Part II Glassmaking, vol. 26, no. 6, 2006-12.