New Compact Temperature Controller with Fuzzy Logic

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1. Introduction

PID control techniques are increasingly used today for regulating temperatures in mechanical systems. Operations of PID control are understood fairly well. It is, however, theoretically impossible to pursue both improvement in disturbance response characteristics and suppression of overshoot at the same time. PID tuning is required to achieve the best combination of these two elements, but the work involves some complication. First of all, it is in large part empirical, rather than theoretical, and approaches differ depending on what to control.

Solutions to PID tuning problems have been studied from various angles. One of them is to utilize inference based on Fuzzy theory. Temperature controllers using Fuzzy logic algorithms have emerged in the market.

Figure 1 shows Fuji Electric's family of temperature controllers. As shown in the figure, the PYZ Series, marketed in 1987, is a general-purpose model having minimum required functions. Cost performance is emphasized in this line of products. The PYW and PYV Series are more recent additions to this family. The PYH Series, marketed in 1988, incorporate RS-485 for general-purpose transmission, and can also be connected to our sequencer MICREX-F through T-link transmission. This line of products can therefore be integrated into a temperature control system. All these

Fig. 2 PYX4 (48×48×115 mm)

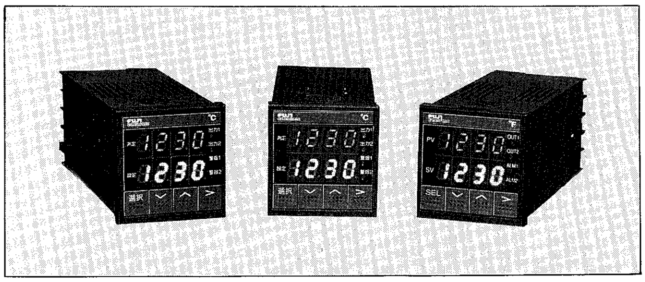
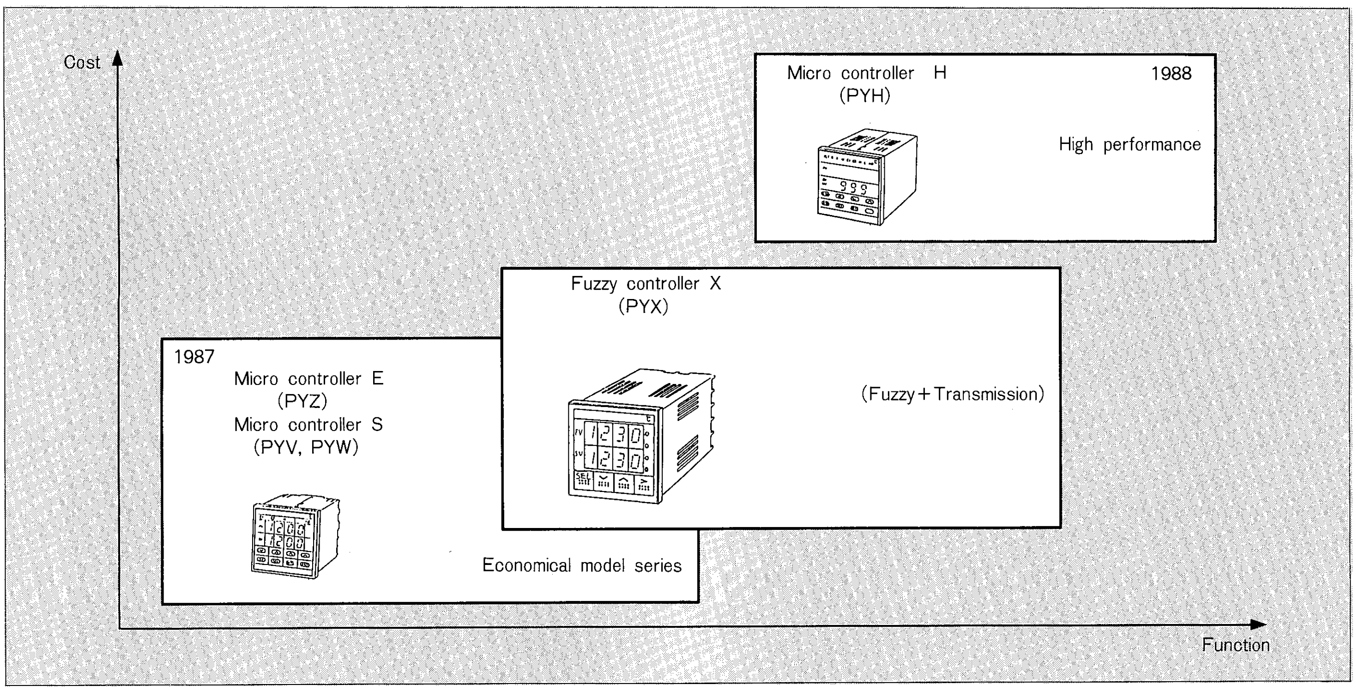


Fig. 1 Fuji Electric's family of temperature controllers



products use PID control. Temperatures are controlled through auto-tuning of PID. Although various control sophistications are provided in these models, use of anti-reset windup and on-site fine adjustments of PID constants are needed to achieve the most efficient combination of suppression of overshoot and improvement in disturbance responses.

To release the user from these complicated procedures, FUJI developed the Fuzzy controller PYX Series, which use Fuzzy inference. This series of models is capable of preventing overshoot, while at the same time, largely improving disturbance responses.

As equipment becomes more compact and systematized, demands for temperature controllers which are smaller and more system-oriented will increase. These factors were taken into account during development of the Fuzzy controller PYX models.

2. Outline of Fuzzy Temperature Controller (PYX)

Our newest development, the Fuzzy temperature controller PYX4 is shown in **Fig. 2**. PYX4 is the first 48 x 48mm (1/16 DIN) class model in the industry which incorporates the Fuzzy inference engine.

It features dual control, program controlled ramp and soak operation for up to four sets of ramp and soak (eight segments), general-purpose transmission (RS-485), and analog transfer output (1 to 5V DC), dual setting. All of these features are noteworthy for an instrument of this size.

As shown in **Fig. 1**, PYX4 is an intermediate model in the family of products, ranked between economical models PYZ/PYV/PYW and high-performance model PYH. Functions of PYX4 are explained in the subsequent sections.

3. Fuzzy Inference

In PID controls, there is an inverse relation between improvement in disturbance response characteristics and suppression of overshoot.

One of solutions to this problem is a PID control with two-degrees of freedom. Although there are several ways of using this control method, explanations are given with the target value filtering type PID control with two-degrees of freedom as an example.

When we say PID control, we usually refer to the PID control with one-degree of freedom. Its functional block diagram is shown in **Fig. 3**. As the figure clearly indicates, this control method uses only one set of tuning parameters (P, I, and D). This means priority should be given in tuning to either disturbance response characteristics or suppression of overshoot.

In contrast, the target value filtering type PID control with two-degrees of freedom use three additional coefficients, α, β, and γ in the target value filtering unit. Its functional block diagram is shown in **Fig. 4**. The complication of this control method is that you need to tune as many as six parameters (P, I, D, α, β, and γ). What is more, the two-degree freedom coefficients are strongly process-dependent and difficult to determine.

Operations such as temperature regulation should be simple and easy. In this sense, the problem is how to achieve control without the need for tuning. Fuji's solution is the use of Fuzzy inference which mimics the human way of reasoning.

Fuzzy inference is the quantification of output values of ambiguous human explanation such as "big," "small," and "medium" using the if-then rule and a membership function which represents the degree of ambiguous explanation. You can get a non-linearity having a high degree of freedom by diversifying this membership function. In other words, controllability can be improved in any field of control with a suitable combination of the rule and membership function.

Many consumer products currently on the market incorporate a Fuzzy inference engine, with unique applications depending on their use. There are products using Fuzzy theory to suppress overshoot and improve disturbance response characteristics by means of PID with two-degrees of freedom, and products which modify set values internally to improve overshoot based on Fuzzy theory.

Fig. 3 One-degree of freedom PID

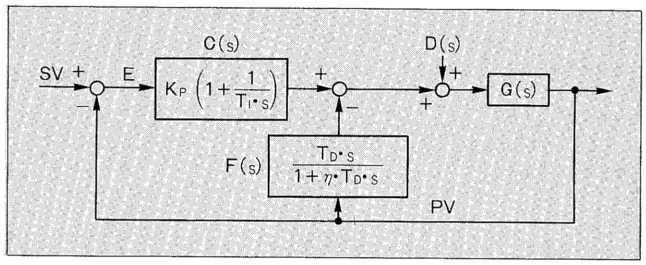


Fig. 4 Two-degrees of freedom PID (Target value filtering type)

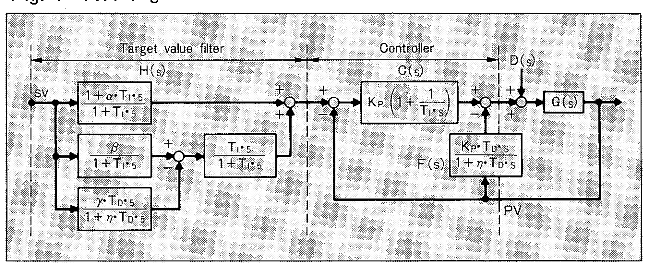


Fig. 5 Functional block diagram of PYX

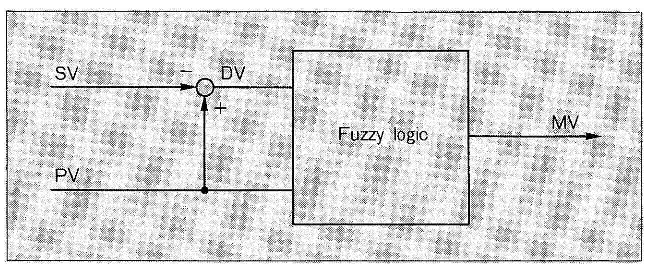


Fig. 6 PYX control chart

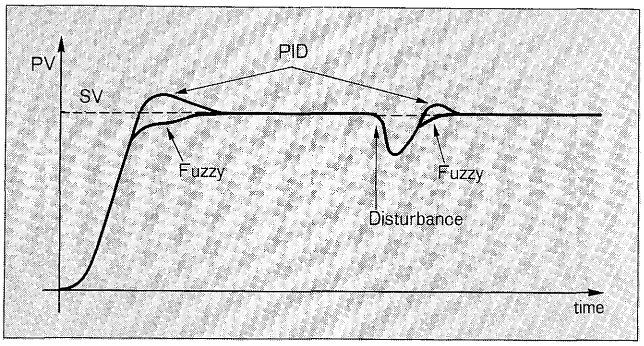


Fig. 7 Integrated instrumental system

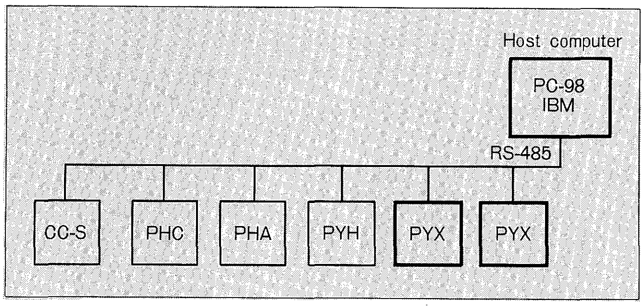


Fig. 8 4 ramp soak program

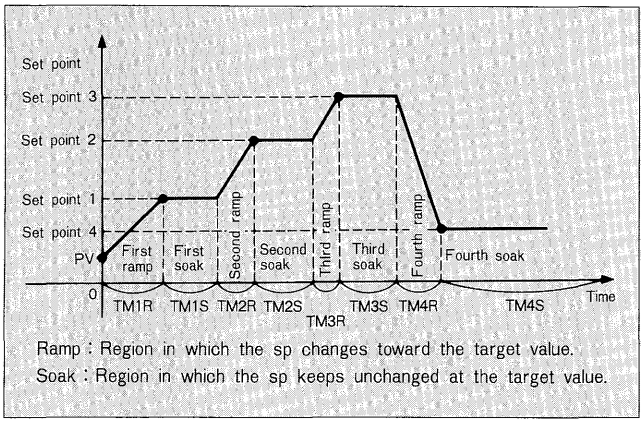


Figure 5 shows a functional block diagram of our recent development, the Fuzzy controller PYX.

The PYX series attains both suppression of overshoot and improvement in disturbance response characteristics using non-linearity, which is one of the features of Fuzzy inference.

Figure 6 shows an example of an actual process controlled by temperature controller PYX based on Fuzzy inference. Overshoots occur under PID control, whereas there is none under Fuzzy control. The time necessary for adjustment is almost the same in both control methods, and the response to disturbances are obviously quicker under Fuzzy control than under PID control.

Table 1 PYX specifications

Input type	Multi input
Output	Relay, SSR drive, Current
Control function	PID/FUZZY
Dual output	Available
Transmission function	RS-485
Ramp soak function	4 Ramp soak
Heater break detection	Available (with current monitor)
Loop break detection	Available
2 set points	Available
Alarm function	Multi alarm
Auxiliary analog output	Available (1 to 5V DC)
Indication accuracy	0.5%FS
Sampling rate	500 mS
Power supply	100 to 240V AC
External dimensions	48×48×115 mm (PYX4)

4. Other Features of Temperature Controller (PYX)

In this section, the features of PYX other than those based on Fuzzy control, which were already covered in the previous section, are explained. **Table 1** lists PYX specifications.

PYX Features:

1. General-purpose transmission (RS-485)
2. Program control for up to four sets of ramp and soak
3. Analog transfer output
4. Dual setting
5. Heater line break alarm
6. Multi-alarm system

4.1 General-purpose transmission (RS-485)

The general-purpose transmission feature makes it easy to build a temperature control system based on a commercial PC. With this system, for instance, several PYX4s mounted on an injection molder can be managed in an integrated manner. Fuji's proprietary CC data line protocol used for transmission allows temperature regulator PYH and recorder PHA/PHC to be connected to the same host. This is useful for building an integrated instrumental system (**Fig. 7**).

4.2 Program control for up to four sets of ramp and soak

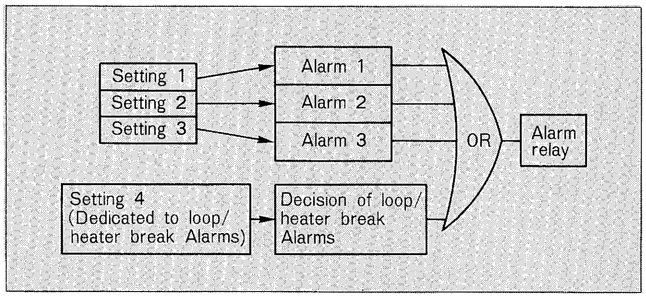
A maximum of four sets of ramp (a section where the set value changes with time) and soak (a section where the temperature is constant) can be entered in the temperature control program (**Fig. 8**). The program can run for up to 800 consecutive hours. A simplified thermostatic oven is one of the applications.

The program can be started and stopped by opening and closing an external contact.

4.3 Analog transfer output

The analog transfer output (1 to 5 V DC) allows the

Fig. 9 Multi-alarm



real-time transfer of one measured variable, set variable, and manipulated variable to an external device. By connecting this feature to the recorder, measured variable and other data can be recorded without the need to provide sensors for the recorder.

4.4 Dual setting

Two set values can be switched by opening and closing an external contact. With an external timer, for instance, set temperatures for the day and night can be switched.

4.5 Heater break alarm

The heater break alarm can be set in a range from 1 to 50A in units of 1A. A heater current monitor is mounted on the instrument, allowing the user to monitor the heater current in units of 1A. This can be used for setting the alarm level.

4.6 Multi-alarm system

Figure 9 shows a functional block diagram of the multi-alarm system. Up to four set values for four different alarms can be defined. These alarms are processed independent of each other, and if one of the alarms is turned on, the alarm relay is turned on.

This system can be used to set alarms for different upper and lower limits, or for multiple alarm generation in a device having a single alarm relay.

5. Conclusion

Our newest, compact temperature controller PYX4 was introduced along with its features.

This model in the PYX Series provides highly precise temperature control based on our unique Fuzzy algorithms. In addition, it supports peripheral functions that existing instruments of the same size (48x48 mm, 1/16 DIN) cannot.

As equipment becomes more compact, and total automation is aggressively promoted in the industry, more compact and higher performance temperature controllers are inevitable. The temperature controller PYX4 is a product taking a step forward to meet such user's needs. Fuji Electric will continue to make every effort to satisfy our users in the future.