RESEARCH ON TEMPERATURE CONTROL OF HEATING FURNACE WITH INTELLIGENT PROPORTIONAL INTEGRAL DERIVATIVE CONTROL ALGORITHM

by

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In view of the problems of large overshoot and large oscillation frequency in current furnace temperature control, based on the development of intelligent control theory, expert control, fuzzy control, and neural network control in intelligent control theory are combined with proportional integral derivative (PID) control. The intelligent PID control algorithm is used to carry out numerical simulation and experimental research on these several control algorithms. The results show that the adjustment effect of the intelligent PID control algorithm is significantly better than the traditional PID control algorithm. Among them, the fuzzy self-tuning PID control algorithm and the fuzzy immune PID control algorithm are feasible in the application of furnace temperature control. The neural network PID control algorithm It also has good development and application potential.

Key words: *PID control algorithm, heating furnace, temperature control system, single chip microcomputer*

Introduction

In this control object, the resistance heating furnace power is 8 kW, which is powered by 220 V AC, and is controlled by two-way thyristor, fig. 1. The design is temperature controlled for a temperature zone, and the temperature range is required to be controlled from 50-350 °C. The temperature control accuracy of the insulation phase is plus or minus one degree. Select the appropriate sensor, the computer output signal is converted and the voltage across the heating resistor is controlled by the triac controller. The object asks the temperature control mathematical model:

$$G(s)=\frac{K_d e^{-\tau s}}{T_d s+1} \tag{1}$$

where time constant T_d = 350 seconds, amplification factor K_d = 50, lag time τ = 10 seconds control algorithm selection change PID control [1].

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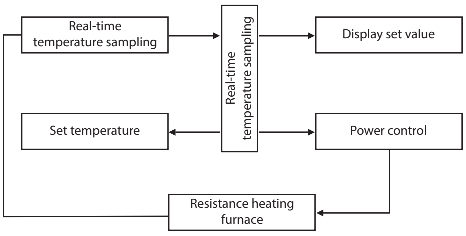

Figure 1. System overall structure

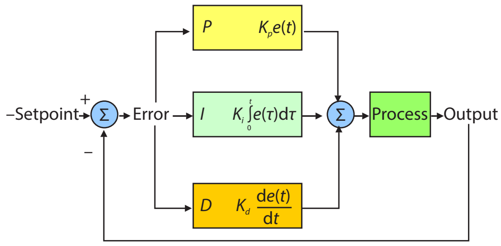

Figure 2. Simplified schematic diagram of the position PID control algorithm

Control system modelling and digital controller design digital PID control algorithm

The differential equation describing the continuous time PID algorithm is changed into the difference equation describing the discrete-time PID algorithm. Figure 2 shows simplified schematic diagram of the position PID control algorithm:

$$\frac{1}{T}\int_0^t e(\tau)\mathrm{d}\tau = \frac{T_s}{T_i}\sum_{j=0}^{k} e(j) \tag{2}$$

When integrating with a rectangle:

$$T_d\frac{\mathrm{d}e(t)}{\mathrm{d}t} = \frac{T_D}{T_S}\left[e(k)-e(k-1)\right] \tag{3}$$

Differential differentiation instead of differential:

$$u(k) = K_p + \left[e(k) + \frac{T_s}{T_i}\sum_{j=0}^{k}\left\{e(j) + \frac{T_D}{T_s}\left[e(k)-e(k-I)\right]\right\}\right] + u_0 \tag{4}$$

From the previous formula:

$$u(k) = K_p + e(k) + K_I\sum_{j=0}^{k} e(k) + K_D\left[e(k)-e(k-I)\right] + u_0 \tag{5}$$

where u_0 is the base value of the control quantity, *i. e.* the control at $k = 0$, $u(k)$ – the control of the k^{th} sampling time, K_p – the proportional amplification factor, K_I – the integral amplification factor, K_D – represents the differential amplification factor, and T_S – the sampling period [2]:

$$K_I = \frac{K_P T_S}{T_I}, \qquad K_D = \frac{K_P T_D}{T_S} \tag{6}$$

Equation (5) is a non-recursive form of the digital PID algorithm, called the full-quantity algorithm. In the algorithm, in order to sum, all past values $e(j)$ ($j = 1, 2, 3,...,k$) of the system deviation must be stored. This algorithm yields the full output $u(k)$ of the control quantity, which is the absolute value of the control quantity. In the control system, this amount of control determines the position of the actuator, for example in valve control, the output of this algorithm corresponds to the position (opening) of the valve. Therefore, this algorithm is called a *location algorithm*. When the actuator needs not the absolute value of the control quantity, but the increment of the control quantity (for example, to drive the stepping motor), the PID *incremental algorithm* is needed. Determined by position algorithm:

$$u(k-1)=K_p\left[e(k-1)+\frac{T_s}{T_I}\sum_{j=0}^{k-1}e(j)+\frac{T_D}{T_s}e(k-1)-e(k-2)\right]+u_0 \tag{7}$$

Find again:

$$\Delta u(k)=u(k)-u(k-1) \tag{8}$$

Incremental algorithm for control quantity:

$$u(k)=K_p\left\{e(k)+\frac{T_s}{T_I}\sum_{j=0}^{k}e(j)+\frac{T_D}{T_s}\left[e(k)-e(k-1)\right]\right\}+u_0 \tag{9}$$

Equation (9) is called an incremental PID algorithm. After the incremental PID algorithm (9) is merged:

$$\Delta u(k)=q_0e(k)+q_1e(k-1)+q_2e(k-2)$$
$$q_0=K_p\left[1+\frac{T_S}{T_I}+\frac{T_D}{T_S}\right],\quad q_1=-K_p\left[1+2\frac{T_D}{T_S}\right],\quad q_2=K_p\frac{T_D}{T_S} \tag{10}$$

Among them, (10) cannot see the expression of PID, and cannot see the direct relationship of P, I, D action, only shows the impact of each error amount on the control. From eq. (10), the digital incremental PID algorithm is enough to store the last three error sample values e(k), e(k – 1), e(k – 2).

Hardware design and implementation

In the detection device, the temperature detection WZP-231 platinum thermal resistance (Pt100) adopts the three-wire connection method, and the sampling circuit is a bridge measurement circuit. The input range is 50~350 °C, and the output is sampled by the measurement circuit. The 5 V voltage is converted by the analog-to-digital conversion chip ADC0809, which is converted into a digital quantity and sent to the MCU for analysis and processing.

Platinum resistance temperature sensor is a temperature sensor made by a certain function of its resistance and temperature. It is widely used for medium temperature (–200 °C due to its high measurement accuracy, large measurement range, reproducibility and stability. Temperature measurement in the range of ~650 °C). The differential pressure signal is much smaller than the theoretical value, and the actual output signal:

$$4.096\left[\frac{R_{Pt100}}{R_1+R_{Pt100}}-\frac{R_{VR2}}{R_1+R_{VR2}}\right] \tag{11}$$

Driver execution part

The hardware output channel mainly includes the control link of the heating resistor, and the core of this control link is the bidirectional thyristor, but the key of the circuit is to design the driving circuit of the bidirectional thyristor. The on/off the triac directly determines the operation and non-operation of the heating resistor [3]. This part is driven by the optocoupler MOC3061 with zero-crossing trigger.

Optocoupler drive circuit

In the drive circuit, because the weak current controls the strong electricity, the weak current is easily interfered by the strong electricity, affecting the working efficiency and real-time performance of the system, and even burning the entire system, resulting in irreparable consequences, so it is necessary to add anti-interference measures. Will isolate the strong and weak electricity. The optical coupler transmits signals by light, cuts off the connection between the ground lines of the components, and fundamentally isolates the strong and weak electricity, so that the interference signal can be effectively suppressed. In addition, the optocoupler provides better bandwidth, lower input offset drift and gain temperature coefficient. Therefore, the requirement of the signal transmission speed can be satisfactorily satisfied, and the optical coupler is very easy to obtain the trigger pulse, and has the characteristics of reliability, small size, and the like. Therefore, in this system design, the photoelectric isolator MOC3061 with zero-crossing detection is used to drive the triac and isolate the control loop and the main loop. The MOC3061 is a chip that integrates zero-crossing detection and optocoupler trials. The rated voltage at the output is 400 V, the maximum repetitive surge current is 1.2 A, the maximum voltage rise rate dv/dt is 1000 v/μs, the input-output isolation voltage is 7500 V, and the input control current is 15 mA.

Drive circuit related component selection

The R25 and C10 form an absorption circuit and are connected between the two poles of the triac. The absorption loop constitutes a buffer. With the absorption loop, the rate of change of the power supply voltage during the thyristor switching process is limited by R25 and C10. The R25 can suppress the inrush current generated when the triac is turned on and off. R25 and C10 are selected according to the empirical formula. Generally, C10 takes 0.01~1.0 uF, and R25 takes several ohms to tens of ohms. In this circuit, R25 takes 39 ohms and C10 takes 0.01 uf [4].

The R27 is a current limiting resistor that limits the output drive current of the MOC3061 by dividing the peak value of the supply voltage by the allowable repeat current of the triac. In this circuit, R27 takes 300 Ω.

The R26 since the MOC3061 also has an output current less than or equal to 500 mA in the output shutdown state, the R26 shunt is added to eliminate the influence of this current on the triac to prevent the triac from false triggering and improve the reliability of the system.

Bidirectional thyristor circuit

In this design, considering the stability of the grid voltage and the two-way thyristor model currently on the market, the bidirectional thyristor BT136 with an operating voltage of 400 V and an on-state current of 4 A was selected. The single-chip microcomputer is used to control the conduction angle of the two-way thyristor. At different times, the single-chip microcomputer is used to send a trigger signal to the control terminal of the triac to turn it on or off, to realize the difference of the effective value of the load voltage, to achieve the purpose of voltage regulation control. The details are:

– The zero-crossing triggering link is completed by the hardware, that is, thzero-crossing trigger signal is performed every 10 ms under the power frequecy volage, and the signal is used to synchronize with the single chip microcomputer.
– The zero-crossing detection signal is connected to the P2.3 port of the single-chip microcomputer, and the loop detection is performed by the single-chip microcomputer, and then the delay trigger is performed.

Power section

The power required by this system has 220 V AC mains, DC 5 V voltage and low voltage AC, so it needs transformer, rectifier and voltage regulator chip to form the power circuit.

The power transformer converts the voltage of the AC grid 220 V into a required voltage value, and then changes the AC voltage to a pulsating DC voltage through a rectifier circuit. Since the pulsating DC voltage also contains a large ripple, it must be filtered by a filter circuit to obtain a smooth DC voltage. However, such voltages also vary with grid voltage fluctuations (typically around ±10% fluctuations), load and temperature changes. Therefore, after the rectification and filtering circuit, a voltage stabilizing circuit is also required. The function of the voltage regulator circuit is to maintain the output DC voltage stable when the grid voltage fluctuates, the load and the temperature change. The rectifier device adopts diode bridge rectification, and the voltage regulator chip adopts 78L05. The voltage is stabilized at 5 V with the capacitor, which is used for the weak part of the control circuit, the measurement circuit and the drive execution circuit. In addition, 220 V AC mains is the voltage across the heating resistor, controlling the power of the heating resistor by controlling the conduction and deactivation of the triac. The low-voltage alternating current is the voltage on the secondary side of the transformer. The zero-crossing point of the alternating current is detected by the zero-crossing detection circuit. After being sent to the single-chip microcomputer, the conduction angle of the two-way thyristor is determined by the control program to achieve the purpose of controlling the heating resistor power.

Software design

The application of this system mainly consists of a main program, an interrupt service program and a subroutine. The main program's task is to initialize the system, implement parameter input, and control the normal operation of the furnace. The main program is mainly composed of system initialization, data acquisition and processing, and intelligent reasoning, fig. 3. System initialization includes setting the bottom of the stack, the working register set, the initial value of the control amount, the sampling period, the interrupt mode and status, the working mode of the timer, the initialization of the 8255, and the initialization of the MAX1232. The data acquisition and processing mainly includes real-time collection of the furnace temperature signal of the heating furnace, calculating the difference between the actual furnace temperature and the ideal value and the rate of change of the temperature difference, and filtering and limiting the temperature of the furnace temperature signal.

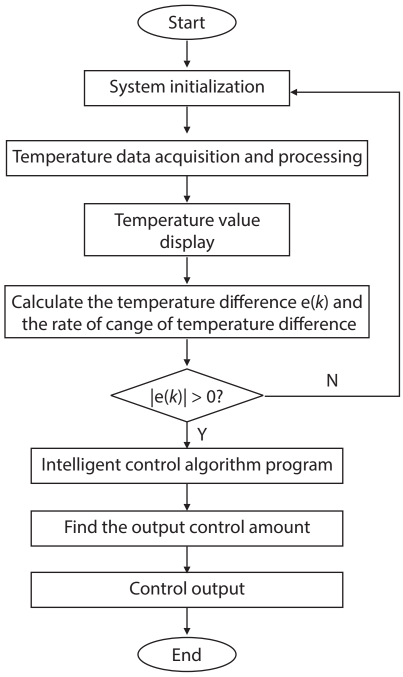

Figure 3. System main program

The software of the control system mainly includes: sampling, scale conversion, control calculation, control output, interrupt, display, alarm, adjustment parameter modification, temperature setting and modification. The control algorithm adopts digital PID adjustment, applies incremental control algorithm, and improves the integral term and the differential term to achieve better control effect. Considering that the furnace is a non-linear, time-varying and distributed parameter system, this paper adopts a new intelligent control algorithm. It fully absorbs the theoretical results of mathematics and automatic control, and combines with qualitative knowledge to achieve long-term complementarity and achieve better results in real-time control.

Analog to digital converter module

The ADC0809 is a typical successive approximation 8-bit A/D converter. It consists of eight analog switches, an 8-bit A/D converter, a three-state output latch, and an address latch decoder. It allows eight channels of analog time-sharing input, and the converted digital output is tri-state (bus type output), which can be directly connected to the MCU data bus. The ADC0809 is powered by a +5 V supply and has an external operating clock. When the typical operating clock is 500KHz, the conversion time is about 128us [5].

Clock signal: Since ADC0809 has no chip select, the circuit adds NAND gate 74LS02 for read/write control of ADC0809. The single-chip microcomputer adopts a 6 MHz/s crystal oscillator, and the ALE outputs a 66 MHz/s clock signal, which is divided by a 74LS74 flip-flop 2 to obtain a 500 KHz clock signal, which is connected to the clock terminal CLK of the ADC0809.

Channel selection: The three-channel selection terminals ADDA, ADDB, and ADDC are connected to the lower three bits P1.0, P1.1, and P1.2 of the data line P1 port, and the channel selection is performed by the data line, and P1.0 and P1.1 are used. The three people in P1.2 decided to choose which channel.

The ADC0809 starts: ADC0809 start terminal START, address stored end ALE are active high. Connect START and ALE to the output of the 74LS02. When the two inputs/WR and P3.5 of the NOR gate 74LS02 are both low, their output is high, and the external I/O port is written.

Reading of converted data: When the conversion ends, the EOC output is high. Data read processing can be performed by query and interrupt methods. The output allows the OE terminal to be high, and the 8-bit conversion data D0~D7 are output to the data line. The OE terminal is high only when P3.5 and /RD are both low. Execute external I/O port read operation /RD is low. End of conversion flag EOC: End of conversion flag EOC is connected to /INT1 of the microcontroller via the inverter, ie, once the conversion is completed, the external interrupt 1 requests an interrupt, fig. 4.

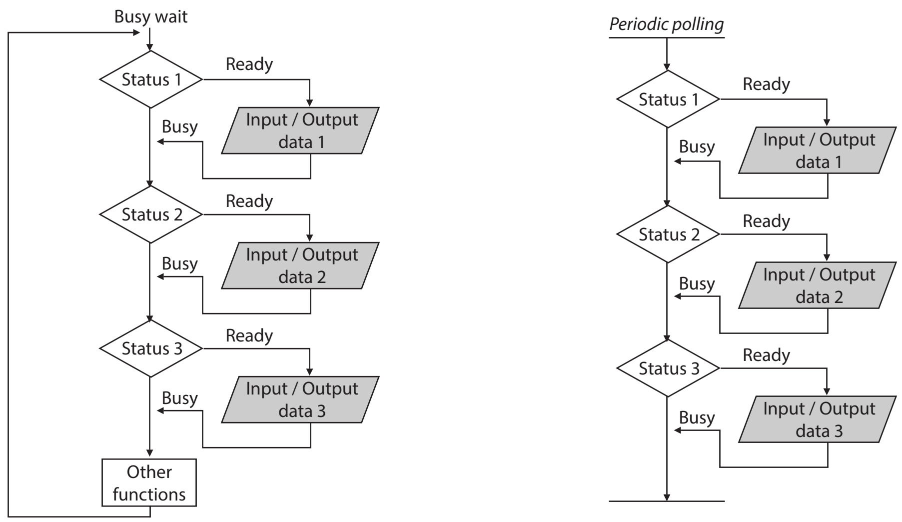

Figure 4. The A/D conversion and interrupt service program flow chart

The LED display module

The 8-segment LED display is the most commonly used display device and is divided into two types: common anode and common cathode [6]. The common anode LED connects the anodes of all the LED together as a common terminal. When the common terminal is connected to a high level and the cathode of a certain section of the LED is connected to a low level, the corresponding field is illuminated. The common cathode LED connects the cathodes of all the LED together as a common terminal. When the common terminal is connected to a low level and the anode of a certain segment is connected to a high level, the corresponding field is illuminated. The display method of the LED digital tube is divided into a dynamic display as a static display,

Dynamic display

Dynamic display means that the microcomputer scans the display device periodically. In this method, the display device works in a time-sharing manner, and only one device can be displayed at a time. However, due to the persistence of human vision, it is still felt that all devices are being displayed.

Static display

The static display, after being output by the microcomputer once, can maintain the display result until the next time the new display model is sent. This display takes up less time and displays reliable. Through comparison and analysis of the program, both sets of digital tubes in this design use a common cathode static display, fig. 5.

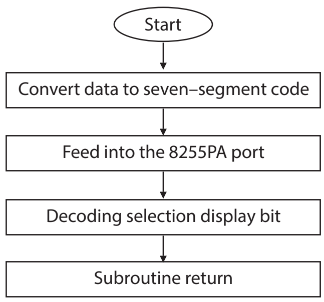

Figure 5. The subroutine

Alarm module

According to the design requirements, in the heat preservation phase, the temperature control accuracy is plus or minus 1 degree, so when the temperature drops or rises 2°, it is a fault state, and an alarm reminder is needed. Therefore, the buzzer and the light-emitting diode are applied in the circuit design. When the system is in normal operation, the green LED is lit [7]. When the fault occurs, the red LED lights up and the buzzer sounds to remind the operator. The alarm status can be reset automatically after the button is reset and the system returns to normal, fig. 6.

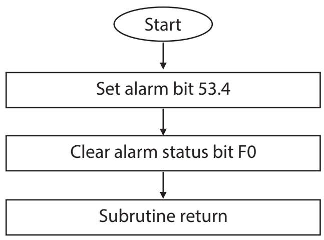

Figure 6. Alarm subroutine

Keyboard module

In this design, the input device uses a 4 × 4 matrix keyboard. When the *Set* button is pressed, the keyboard interrupt service program is triggered, and the program-controlled scan method determines which key is pressed and performs the corresponding action. The task of program-controlled scanning is:
– First determine if there is a key press. Method: Make all row outputs low and then read the column values from port A. If no key is pressed, the reading value is FFH. If there is a chain press. It is not FFH.
– Remove key jitter. Method: Delay 10-20 ms, once again determine whether there is a key press. If there is still a key press at this time, it is considered that there is indeed a key in the keyboard that is in a stable closed period.

– If there is a key closure, the key value of the closed key is obtained. Method: Scan the keyboard progressively. The program needs to wait for the close button be released before processing it.

Communication module

In this part, the communication between the lower computer and the upper computer is realized, and the real-time data is transmitted to the upper computer for the same coordination and centralized management. The RS232 electrical interface is a single-ended, bipolar power supply circuit. Since the data transmission-line used by RS-232 is unbalanced and is a differential-free reception method, the transmitted signal will be affected when the signal passes through the electrical interference environment. Therefore, the data transmission rate is limited to 20 KB/s; the transmission distance is limited to 15 m, but RS-232 is also the most widely used serial communication interface standard [8].

In this design, considering the convenience of system debugging, RS232 serial bus is adopted. The MAX232 chip is an interface circuit designed by Maxim for the RS-232 standard serial port of the computer. It is powered by a single +5 V power supply.

Experimental test and verification results

In order to verify the actual control performance of the designed algorithm on the furnace temperature of the furnace, the LABS1000 kit developed by Advantech was used to conduct experimental research by controlling the temperature of a closed small space. The temperature rise of the confined space is achieved by controlling the voltage across the thermal resistance of the cement, while the temperature drop is achieved by controlling the fan speed, which is measured by a thermocouple. In the experiment, the set value of the temperature of

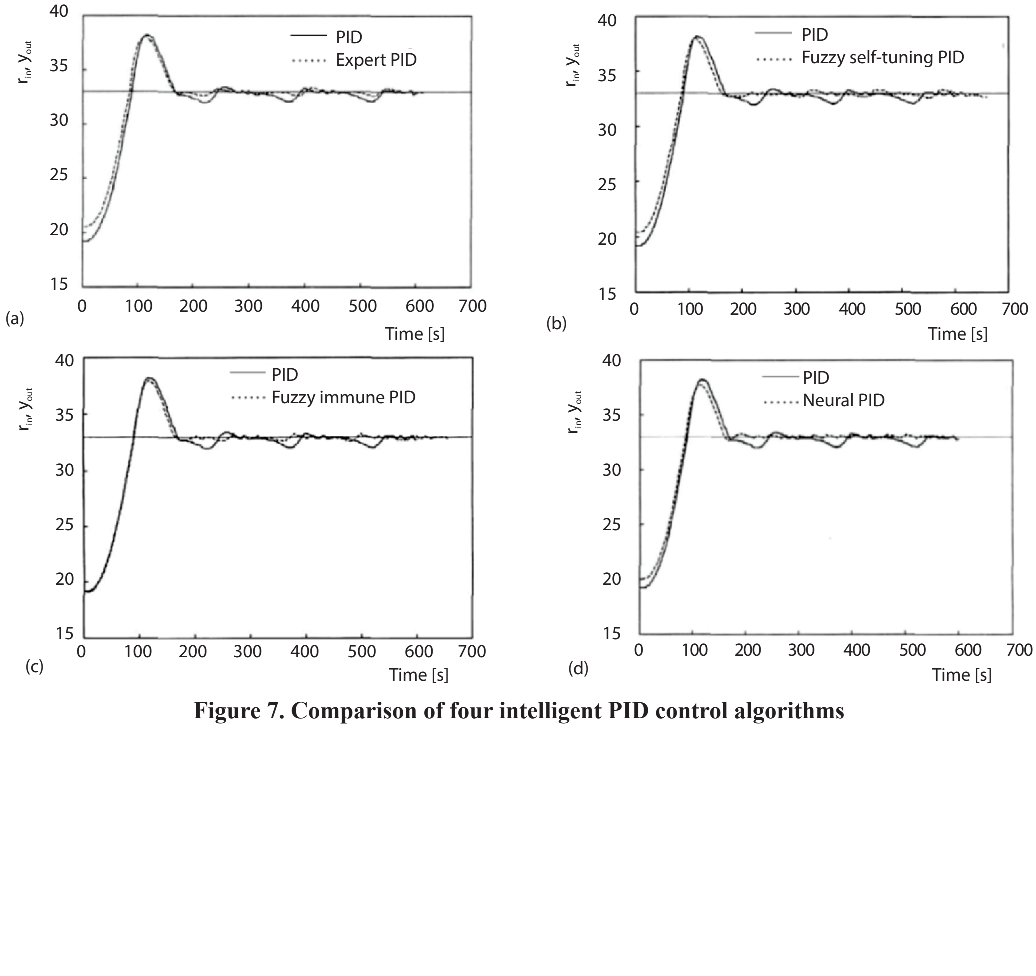

Figure 7. Comparison of four intelligent PID control algorithms

the closed space is set to 33 °C, and the temperature control experiment is carried out by the intelligent strategy of the above design. The experimental results are shown in fig. 7 shown.

Conclusion

The fuzzy self-tuning PID control algorithm and the fuzzy immune PID control algorithm are more feasible in the temperature control of the heating furnace because of its simple and easy to control and actual control effect. The neural network can approach any non-parallel processing due to its own parallel processing. The advantages of linear systems and the future are also very promising. The results of this study have made a useful exploration of the practical application of intelligent control algorithms in industrial furnace temperature control.

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