Adaptive Re-tuning of PID Parameters by Health Indexes - Naotoshi Taniguchi

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Introduction:

PID parameters of temperature controllers commonly used for semiconductor equipment should properly tuned to avoid chamber to chamber variation. But the parameters are usually tuned to the standard chamber and distributed to other chambers neglecting the difference between chambers as shown in figure 1. And the tremendous amount of human efforts are required if each chamber is tuned individually. We have developed the method to tune the parameters simply and confirmed to get the better chamber matching.

Health Indexes detection on Local PID controller:

By using the local PID controller, a normalized response R=Kp/Tp [1] (one of the health indexes) can be detected. Equation (1) is an internal model Pm of a controlled system P that is approximated into first order lag with dead time.

$$Pm = Km \exp(-Lm\, s) / (1 + Tm\, s) \quad (1)$$

Where in equation (1), Km is a model gain, Tm is a model time constant and Lm is a model dead time and they correspond to the process gain Kp, the process time constant Tp and the process dead time Lp.

For detecting the dynamics of P, the ratio ΔPV and the ratio ΔPVm are measured in the step response control (Figure 2). Then the normalized response R=Kp/Tp is defined based on equation (2).

$$Km / Tm : Kp / Tp = \Delta PVm\_max : \Delta PV\_max \quad (2)$$

A time difference between ΔPV_max point and ΔPVm_max point (TD in Figure 2) is another index that shows an estimated dead time Lp.

The method to improve the chamber matching:

At first, PID parameters for standard chamber, P_0, I_0, D_0 are described as in equations (3), (4), and(5). Ai、Bi、Ci are the constants.

$$P\_0 = Ai(Kp/Tp)\, Lp \quad (3)$$

$$I\_0 = Bi\, Lp \quad (4)$$

$$D\_0 = Ci\, Lp \quad (5)$$

And we can get the normalized response function R=Kp/Tp[1] in the initial runs of the standard chamber along with the health index of R and TD as (R_0、TD_0).

When those PID parameters are copied to the same type of chamber, the controllability often varies due to the difference between chambers. To get the better PID parameters, we have developed the simple method defined as Settled state ratio[2] (STL) and Overshoot ratio[3] (OVS) as indexes of controllability as described in equation (6) and (7).

$$STL = Qt / (1 + Tfs) \quad (6)$$

$$OVS = Qov / \Delta PV sp \quad (7)$$

In (6), Qt is a score for the setting error range and Tf is the time constant. In (7), Qov is a quantity of the overshoot and ΔPVsp is the ratio when PV reached the set point SP.

Adaptive Re-tuning on another chamber:

The health Indexes are obtained from every control run. And new PID parameters can be obtained when needed as described in equations (8), (9), and (10).

$$P\_new = P\_0\, (R\_x / R\_0)\, (TD\_x / TD\_0) \quad (8)$$

$$I\_new = I\_0\, (TD\_x / TD\_0) \quad (9)$$

$$D\_new = D\_0\, (TD\_x / TD\_0) \quad (10)$$

Experiments:

Table 1 shows a series of experiments carried out in a furnace for temperature control with PID controller.

1st rin is the case in the standard chamber that the PID parameters were properly tuned that gave (R_0, TD_0) as the health Index.

2nd run was carried out at the different load in the furnace which is equivalent to the chamber which has difference with the 1st one. So, the controllability of this run is worth than the 1st run.

In the 3rd run, PID parameters were tuned according to the equations (8) to (10). The controllability was improved as shown in Figure3. By continuing this procedure, the difference of the controllability should be able to be minimized.

Conclusions:

We have demonstrated an adaptive re-tuning method to minimize the difference between chambers. This method can be applied to some other type of PID controllers besides temperature controllers to get uniform controllability of many different chambers By placing this method in IoT platform properly, it might be able to contribute to reduce variations of the processes of semiconductor manufacturing.

References:

[1] M. Tanaka : Patent JPB-4481953 (2010)
[2] M. Tanaka : Patent JPB-6200261 (2017)
[3] M. Tanaka : Patent JPB-4417915 (2010)

Figure 1. Distributed PID parameters to different chambers

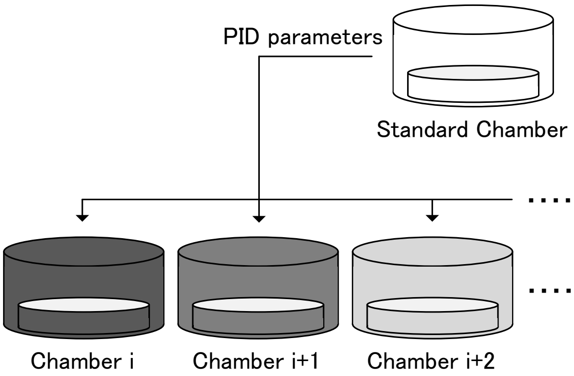

Table 1. Results of experiments

	P	I	D	R	TD	STL	OVS
1st	1.5	80	40	0.0112	158	89 sec.	28.2
2nd	1.5	80	40	0.0108	139	256 sec.	44.4
3rd	1.3	70	35	0.0086	171	117 sec.	34.4

P_3rd = 1.5 * (0.0108 / 0.0112) * (139 * 158) = 1.3

I_3rd = 80 * (139 / 158) = 70

D_3rd = 40 * (139 / 158) = 35

Figure 2. PV and PVm in step response

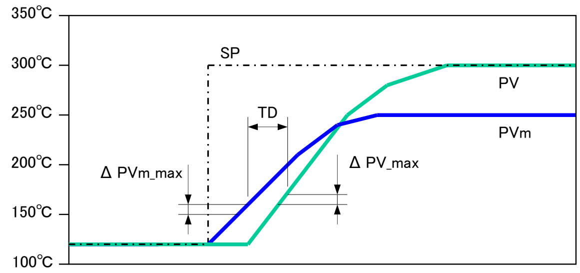

Figure 3. Results of Experiments