A MFC Control Algorithm Based on Intelligent Control

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Abstract: The Mass Flow Controller(MFC) has become crucial in semiconductor manufacturing equipments. It is an important element because the quality and the yield of a semiconductor process are decided by the accurate flow control of gas. Therefore, the demand for the high speed and the highly accurate control of MFCs has been requested. It is hard to find an article of the control algorithm applied to MFCs. But, it is known that commercially available MFCs have PID control algorithms. Particularly, when the system detects the flow by way of heat transfer, MFC control problem contains the time delay and the nonlinearity.

In this presentation, MFC control algorithm with the superior performance to the conventional PID algorithm is discussed and the superiority is demonstrated through the experiment. Fuzzy controller was utilized in order to compensate the nonlinearity and the time delay, and the performance is compared with that of a product currently available in the market. The control system, in this presentation, consists of a personal computer, the data acquisition board and the control algorithm carried out by LabWindows/CVI program on the PC. In addition, the method of estimating an actual flow from sensor output containing the time delay and the nonlinearity is presented.

In conclusion, according to the result of the experiment, the proposed algorithm shows better accuracy and is faster than the conventional controller.

Keywords: Mass Flow Controller, Fuzzy control, PID, Semiconductor Manufacturing

1. INTRODUCTION

Recently, the development of industry requires the high speed and the high accuracy. Specifically, in the semiconductor manufacturing process such as etching furnace, CVD, wet station, highly accurate control of the gas flow is required. Hence, the importance of Mass Flow Controller(MFC) is prominent[1-3].

MFC adjusts the flow rate of a gas stream to the value which the process requires. Generally, MFC consists of the base frame, the flow sensor, the control valve and the circuit board. The base frame provides the pathway of the main gas flow and the amount of flow is governed by the opening of the control valve. The sensing flow is run through a small bypass, which is proportional to the main flow. In the bypassing tube, the flow sensor is installed to measure the flow rate of the bypass using thermal conduction. The control valve operates by ceramic, solenoid or thermal actuator. The circuit board sends the valve opening signal according to the temperature difference in the flow sensor[2-4]. Recently, MFCs use micro flow sensor[5-6] or integrated micro flow control system[7-8].

It is hard to find an article describing the control algorithm applied to MFCs. But, it is known that commercially available MFCs utilize some PID algorithms. Also, it is known that the control of MFC is difficult because MFCs have inherently a time delay and a nonlinearity, especially when the flow sensor detects the flow by the heat transfer[1].

In this presentation, a fuzzy control algorithm with the superior performance to the conventional PID algorithm is discussed and the superiority is demonstrated through the experiment. Fuzzy controllers can effectively treat the uncertainty by way of human inference. Therefore, the fuzzy control shows good result in such a field as the decision-making problem, the expert system, the artificial intelligence and the system control. Also, because the fuzzy logic control utilizes human experts' knowledge of experience, it is not required a model of the control plant[9].

It is found that the flow sensor which is type of heat transfer, shows time-delayed sensing behavior. In order to estimate the actual flow rate using the sensor, a compensator to the sensor signal is designed and utilized to make whole control loop. The experimental result on the performance of the proposed control algorithm shows better performance than that of a commercial product.

In this presentation, section 2 illustrates about the structure, sensor and the overall structure of general MFCs. The problems about the traditional MFC are followed in section 3. section 4 presents about proposed fuzzy control algorithm. section 5 compared experiment result of a traditional MFC and the proposed algorithm, which is followed by the conclusion in the next section.

2. MASS FLOW CONTROLLER

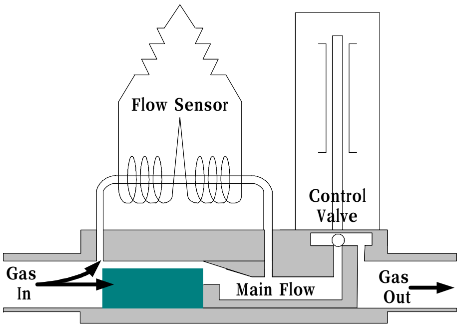

Fig.1. Structure of MFC.

The Fig. 1 shows the overall structure of the MFC. MFC adjusts the flow rate of a gas stream to the value which the process requires. Generally, MFC consists of the base frame, the flow sensor, the control valve and the circuit board. The base frame provides the pathway of the main gas flow and the amount flow is governed by the opening of the control valve. The sensing flow is run through a small bypass, which is proportional to the main flow. In the bypassing tube, the flow sensor is installed to measure the flow rate of the bypass using thermal conduction. The control valve operates by ceramic, solenoid or thermal actuator. The circuit board sends the valve opening signal according to the temperature difference in the flow sensor.

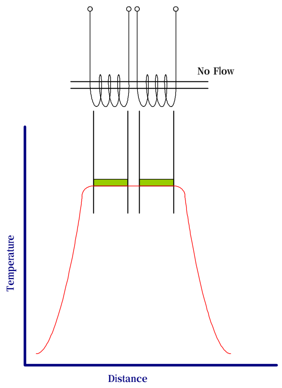

Fig. 2 No flow.

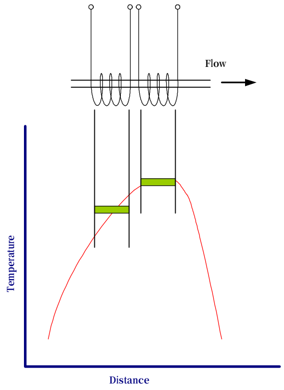

Fig. 3 Flow.

Basic operation principle of the flow sensor is explained as follows. Surrounding the bypass, there are two coils called the upstream coil and the downstream coil are wound. And the constant current is supplied to the coils which results in heating up the coils. In this situation, when there is no gas flow through the bypass, temperatures in those two coils are the same(Fig. 2). However, if there is a flow in the bypass tube, two coils have a different temperature as is shown in Fig. 3. The difference depends on the flow rate of the gas stream. Since two coils consists of the Wheatstone bridge circuit shown in the Fig. 1, those temperatures can be measured by sensing two node voltages of the bridge.

Utilizing the flow sensor, overall MFC operation is illustrated as follows. When there is a certain amount of flow in the main flow, it causes a small amount of flow in the bypass which is proportional to the main flow. The ratio depends on the mechanical structure of the MFC. For example, 1/100 of main flow rate is forwarded to the bypass and then it is possible to calculate the main flow rate from the bypass flow rate..

As stated earlier, the sensing flow rate is measured by measuring the potential difference in the Wheatstone bridge circuit. The voltage is sensed by A/D converter of the circuit board and is utilizing a digital control algorithm, the valve voltage is calculated in the microprocessor of the circuit board. The valve voltage is delivered to the solenoid (for example) valve to open and to adjust the main flow rate.

The MFCs have problems to solve. The main difficulty in controlling MFCs is that the system characteristic is inherently nonlinear. The main objective is to control the amount of flowing gas and the gas flow dynamics is nonlinear to the valve opening and to the temperature of the gas. Also, the valve input voltage has a dead zone, which makes the system to be more nonlinear. The other difficulty is in the flow sensor. The flow rate is sensed by the temperature difference between the upstream coil and the downstream coil and the heat transfer from the flowing gas to the coils is rather slow than it is required to control the system properly.

3. FUZZY ALGORITHM AND FLOW COMPENSATOR

3.1 Structure of MFC control system

Conventional MFCs are known to be controlled by PID control algorithms. The PID algorithm is a linear algorithm and one can expect that there are limitations to control nonlinear plants. In order to control the MFC more accurately, it is natural to consider a nonlinear controller because the MFC has nonlinear characteristic.

Among nonlinear controllers, fuzzy logic controllers(FLC) are well known to have superior behavior in some cases. Requiring no modeling of the plant, the fuzzy logic controller is an easy way to implement human control behavior to be a machine controller.

Fig. 4 shows block diagram of the proposed control system for the MFC.

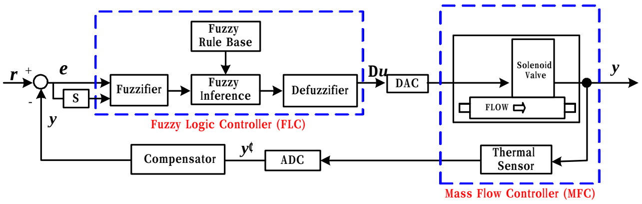

Fig. 4. Block diagram of overall system.

In the figure, r is the reference flow, e is the error flow and e' is the change of error. Δu is the fuzzy controller output, corresponding valve voltage difference applied to the solenoid valve and y is the actual flow rate. Also, y' represents the sensing flow which is the output of the thermal flow sensor.

3.2 Fuzzy control algorithm

In this presentation, the FLC of two input, one output is constructed to control the MFC. Especially the FLC is integral type where the output is Δu . The general FLC structure is shown in the Fig. 5.

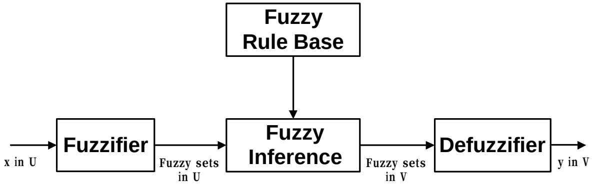

Fig. 5. Basic diagram of fuzzy logic controller.

Fuzzy logic controller is divided into fuzzifier, fuzzy inference, fuzzy rule base and defuzzifier. Fuzzifier maps crisp value to the corresponding fuzzy linguistic value with a membership function. In this paper, the fuzzy singleton is utilized. Linguistic values used in the fuzzy rule base is expressed as membership functions in Fig. 6 for the input ‘error’ and in Fig. 7 for the input ‘change of error’.

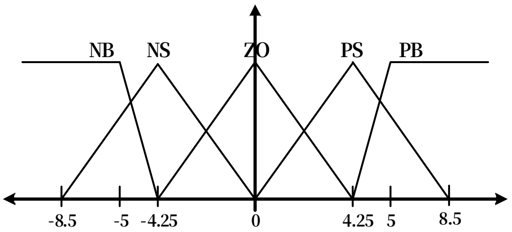

Fig. 6. Membership function of error.

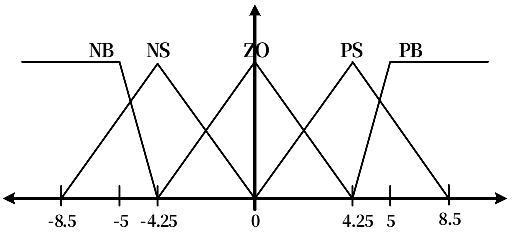

Fig. 7. Membership function of error change.

Also, Fig. 8 shows membership functions of the linguistic values used for the output variable and it shows that memberships are dense in the center in order to control accurately. The fuzzy rules are determined from the experience of experts but in this paper, well-known 5 × 5 symmetric rule table is utilized as in Fig. 9.

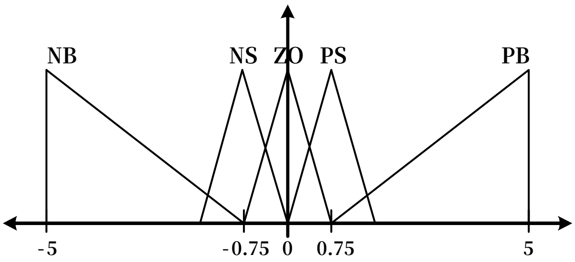

Fig. 8. Membership function of output variable.

e' e	NB	NS	ZO	PS	PB
NB	NB	NB	NS	NS	ZO
NS	NB	NS	NS	ZO	PS
ZO	NS	NS	ZO	PS	PS
PS	NS	ZO	PS	PS	PB
PB	ZO	PS	PS	PB	PB

Fig. 9. Fuzzy rule.

The fuzzy inference is Mandani’s Max-Min method as in Fig. 10 and the defuzzifier uses COG method.

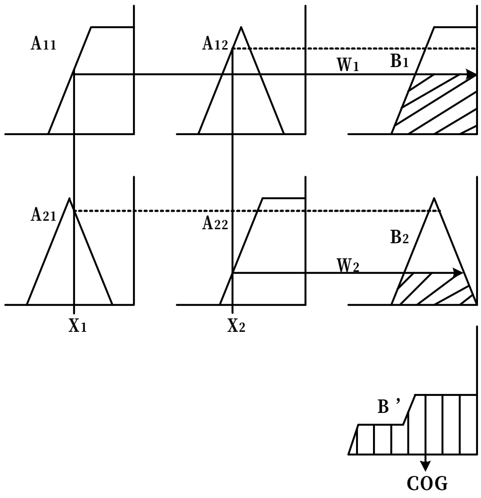

Fig. 10. Max-Min method.

3.3 Compensator for the Flow Sensor

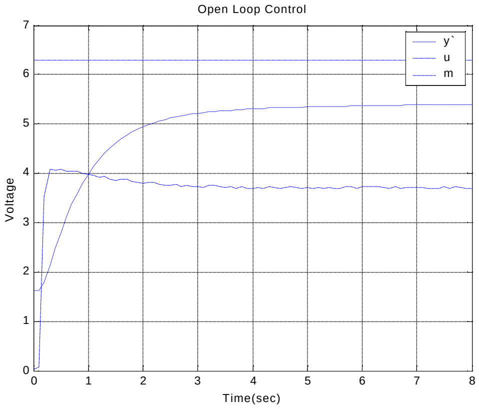

Fig. 11. Open Loop Control.

In order to verify the correct flow of the MFC, the flow rate is measured by the combination of Laminar Flow Equipment(LFE) and a differential pressure sensor. Since the LFE converts the flow rate to the corresponding pressure difference, the flow rate can be measure using differential pressure sensor without heat transfer. Experiment shows that the flow sensor has lagging property as in Fig. 11. In the figure, m is the output of the differential pressure sensor and y’ is the output of the flow sensor equipped inside the MFC.

The figure shows that in order to sense the flow rate promptly, it is required to have a compensator of the flow sensor output. Assuming the behavior is the output of a 1st order low pass filtering, a simple 1st order compensator is utilized to in this paper. The exact parameters are calculated experimentally.

4. EXPERIMENT OF MFC CONTROL

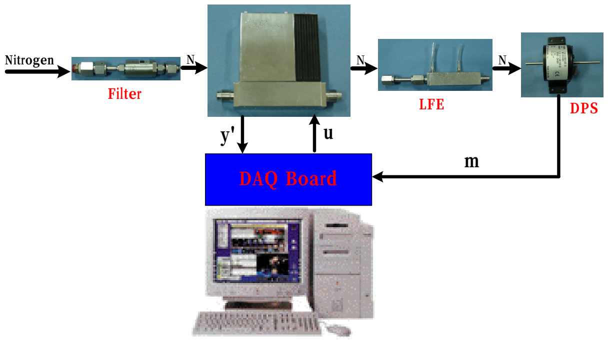

Fig. 12. Experiment environment of MFC.

Fig.12 shows an actual environment of the experiment. The control algorithm is implemented in the PC under the environment of LabWindows/CVI and several sensing and control signals are connected via a data acquisition board. Later on, the control algorithm will be embedded in the circuit board with micro controller.

Nitrogen gas is fed to the MFC after filtering. LFE and differential pressure sensors are used to verify the performance.

4.1 The experimental result of existing MFC

Fig. 13 is the performance of a commercially available MFC. The figure shows that the m has the time delay of 1.4 sec and the rise time of 0.6 sec. With respect to the y', the time delay is 1.4 sec and rise time is 2.4 sec. Observing the u and y', it is easily understand that the time delay is in the MFC.

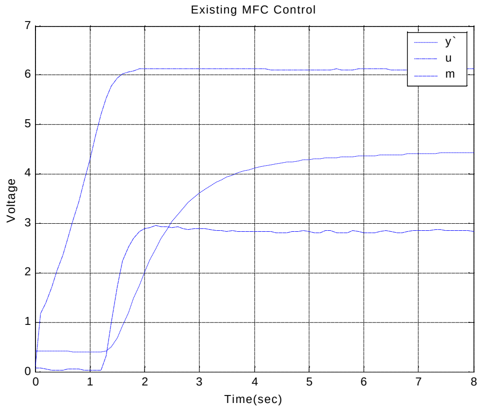

Fig. 13. Result of traditional MFC.

4.2 The result of experiment using the PID controller

Fig. 14 is the performance of the MFC using the PID controller. Reference = 4.5V, Kp = 0.7, Ki = 0.08, Kd = 0.6 are utilized. The result shows that the m has the delay of 1.2 sec, and the rise time of 0.4 sec. y' shows the delay time is 1.3 sec and the rise time is 1.9 sec. The result, y' and m is better than the result of the commercial product.

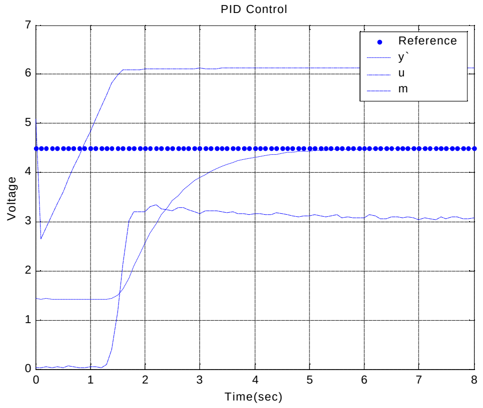

Fig. 14. Experiment result of PID control.

4.3 The experimental result of fuzzy logic controller

Fig. 15 is result of experiment using the proposed fuzzy logic controller. The compensator for the flow sensor is adopted.

The compensator is the 1st order system as K(S+a). Through the repetitive experiment, the parameters K is found to be 2.75 and a is 0.353.

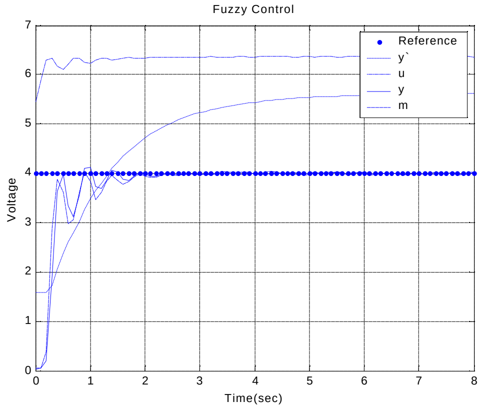

Fig. 15. Experiment result of fuzzy control.

The result shows that, when the m fluctuates, y is almost the same as the m, which means the compensator is working well. The performance of the proposed controller exhibits a fast response with less time-delay and fast rising time. And the result is better than the performance of the other two controllers.

5. CONCLUSION

The MFC is hard to control because of the time delay and nonlinearity inherent in the MFC.

In this paper, a MFC control algorithm with the superior performance to the conventional PID algorithm is proposed and the superiority is demonstrated through the experiment.

Since the proposed controller is nonlinear controller based on fuzzy logic control, the proposed algorithm shows, in the experiment, better accuracy and faster result than the other controllers.

However, the result can be refined and more accurate compensation of the flow sensor should be investigated in the further research.

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