MODELING AND IDENTIFICATION STUDY OF THE VARIATION OF DYNAMIC PRESSURE IN REACTIVE SPUTTERING PROCESS

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ABSTRACT

Automatic control of reactive sputtering process involves controlling the state of the electrical discharge plasma and the definition of control variables. Obtaining a thin film with a determined constant structure and composition, involves maintaining in every part of the substrate and at all time of the deposition process a constant number of collisions, i.e. activated plasma density. This condition is greatly hampered by the dynamics of surface phenomena that occur at the sputtered target. .

Keywords: dynamic pressure, modeling and identification, reactive sputtering process

1. Introduction

Variation of dynamic pressure inside the vacuum chamber has a decisive influence on the formation and maintenance of the electrical discharge parameters (by modifying plasma impedance) and the formation of thin layer structure.[1,2,3]

To achieve an efficient control, which ensures a constant pressure for changes in gas flow process modeling, identification and simulation of physical processes of the dynamical pressure were performed. In general the assumption of separation, the design of automatic control system is divided into two stages, first determining a mathematical model for the process and determining the structure and tuning the regulator [4].

2. Experimental

The experimental measurements were conducted on a reactive magnetron sputtering system. The volume of vacuum chamber is 80 l. The two stage pumping system consists of a TMP with 500l/min pumping rate and a oil sealed fore-vacuum pump. This pumping system provides a base pressure of $2x10^{-6}$ Torr. The process gases flows (argon the inherent gas and N_2 the reactive gas) are controlled with Mass Flow Controllers in range of q = 0-10 sccm. To obtain the required pressure during the sputtering process of $3x10^{-3}$ Torr, the flow rates were: q_{Ar}=6 sccm and q_{N2}=3 sccm.

For pressure measurement we used a compact ceramic gauge type CMR375 from Pfeiffer.

The TMP conductance control was done using a “butterfly” type throttle valve, shown in fig.1.

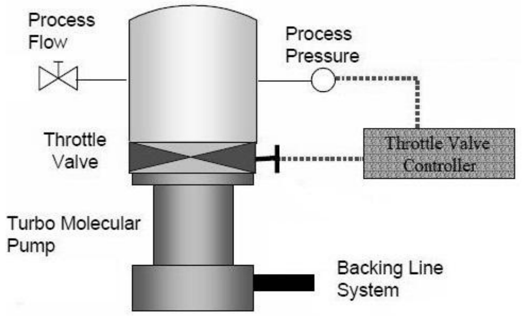

Fig. 1 – Vacuum chamber pressure management system

In downstream pressure control, the valve position is adjusted, changing the system pumping speed and effectively achieving and maintaining pressure regardless of input gas flow. Downstream pressure control has fast response, wide dynamic range and is compatible with all vacuum pumps and most effluent gases.[5]

Figure 2 shows the dynamic pressure variation depending on the valve angle adjustment. The movement of throttle valve was performed with a position controlled DC servomotor in range within 0 to 90 degree with 5 degree resolution and 3 minutes settling time.

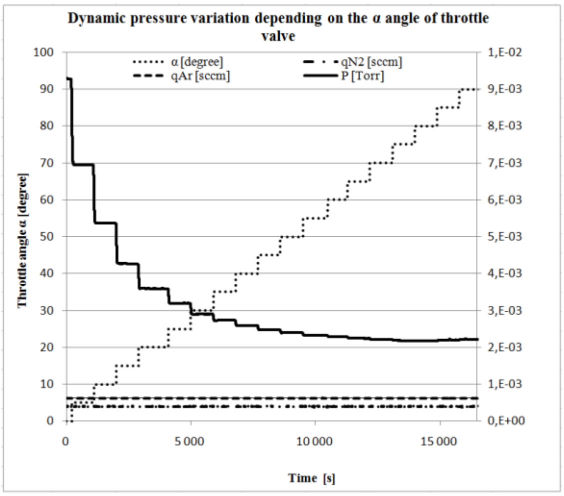

Fig. 2 – Dynamic pressure variation depending on the valve angle adjustment

3. Identification from indicial function of first order systems with dead time

We consider the transfer function:

$$H(s) = \frac{k}{T \cdot s + 1} \cdot e^{-\tau \cdot s} \tag{1}$$

Where, k is the gain, T is time constant and τ dead time. Differential equation takes the form:

$$T \cdot \dot{y}(t) + y(t) = k \cdot u(t - \tau) \tag{2}$$

If input signal has the value:

$$u(t) = 1(t) = \begin{cases} 1 & if\ t >= 0 \\ 0 & if\ t < 0 \end{cases} \tag{3}$$

Analytical form of the system response ($y(0) = 0$):

$$y(t) = k \cdot (1 - e^{-\frac{t-\tau}{T}}) \cdot 1(t - \tau) = \begin{cases} 0 & if\ t \le \tau \\ k \cdot (1 - e^{-\frac{t-\tau}{T}}) & if\ t > \tau \end{cases} \tag{4}$$

Following the steps of parametric model identification, based on experimental measurements k-gain, T-time constant and τ-dead time parameters are calculated. Figure 3 show the model's unit step response.

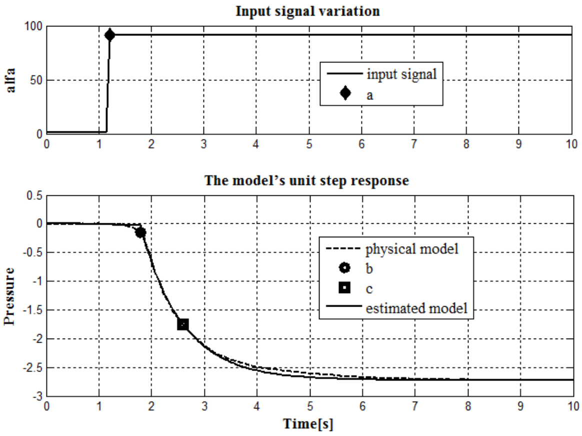

Fig. 3 – The model's unit step response

Using graphic identification methods the transfer function has been defined with the following terms:

$$H(s) = \exp(-0{,}575s) * \frac{-0.02997}{0.8046s + 1} \tag{5}$$

In Matlab Simulink, based on the obtained transfer function the behavior of a PI controller, shown in fig 4., with the following structure has been simulated.

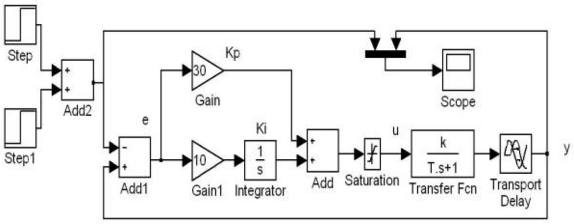

Fig. 4 – Simulated PI controller structure

The transport delay module simulates the real behavior, delay between the change in vacuum line conductance caused by throttle valve movement and the appearance of pressure change detected by pressure sensor mounted on the opposite side with the pumping port.[6] This phenomenon can be seen on fig. 3.

Graphical representation of output of the simulated PI controller is shown in fig. 5:

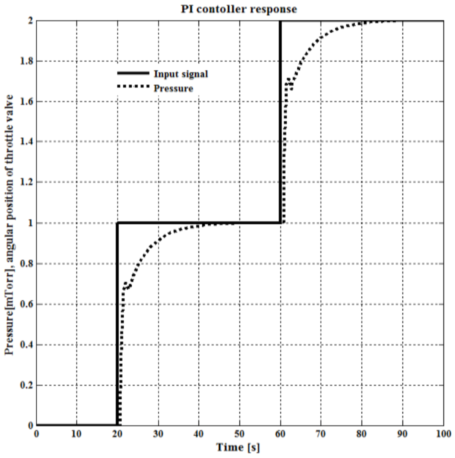

Fig. 5 – The response of PI controller

4. Identification of physical model

We started from the equation of state of the ideal gas:

$$pV = \frac{m}{M}RT \Rightarrow \frac{dm}{dt} = \frac{MV}{RT}\frac{dp}{dt} \tag{6}$$

We can express the flow of exhaust gas q_{out} dependent on the speed of action of the vacuum system according to the α angular position of the throttle valve:

$$q_{in} - q_{out} = \frac{dm}{dt} \tag{7}$$

$$q_{out} = p * S(\alpha) \tag{8}$$

From the above equations:

$$\frac{MV}{RT}\frac{dp}{dt} = q_{in} - p * S(\alpha) \qquad (9)$$

For ease of calculation the dynamic pressure (Torr in Pascal) and inlet flow (volume flow in mass flow) have been converted [6].

$$p = 2{,}5 * 10^{-4}[Torr] = 0{,}033\ [Pa] \qquad (10)$$

$$q_{vol} = 1\ [sccm] = q_{m_{in}} = 0{,}027 * 10^{-6} kg/s \qquad (11)$$

In a stationary state pressure inside the chamber is:

$$p = \frac{q_{in}}{S(\alpha)} \qquad (12)$$

where the speed of action of the vacuum system has the form:

$$S(\alpha) = K * A \qquad (13)$$

A - is the section of pumping port according to the angular position of the butterfly valve α presented graphically in fig.6:

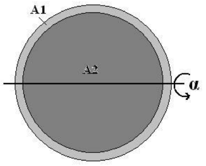

Fig. 5 – The section of pumping port

Total section of vacuum tube has two components, component A1 resulting from the distance between the tube wall and butterfly valve, with constant section and A2 variable component depending on the angular position of the butterfly valve α. Such the action speed of vacuum system takes the form:

$$S(\alpha) = K * \left(A1 + A2 * \cos\left(\frac{\pi}{2}\right)\alpha\right) \qquad (14)$$

If the valve is closed completely α = 0, S(α) becomes:

$$S(\alpha) = K * (A1 + A2 * \sin\alpha)$$
$$= K1 + K2 * \sin\alpha\,. \qquad (15)$$

In stationary state the pressure is:

$$p = \frac{q_{in}}{K1 + K2 * \sin\alpha} \qquad (16)$$

Using these equations we can calculate the mathematical model to physical process.

Based on measurements we have two different cases:

a) If α = 0 °, the pressure p = 1.16 [Pa], K1 has the value:

$$K1 = 0{,}14 * 10^{-6} \qquad (17)$$

b) If α = 90 °, the pressure p = 0.29 [Pa], K2 has the value:

$$K2 = 0{,}41 * 10^{-6} \qquad (18)$$

Finally the derivative of the pressure can be expressed:

$$\frac{MV}{RT}\frac{dp}{dt} = q_{in} - p * S(\propto) \qquad (19)$$

$$\frac{dp}{dt} = 0{,}12 - p * (0{,}1 + 0{,}31 * \sin \propto) \qquad (20)$$

Based on these calculations in Matlab Simulink the simulation of the model with the following structure was done (shown in fig. 6)

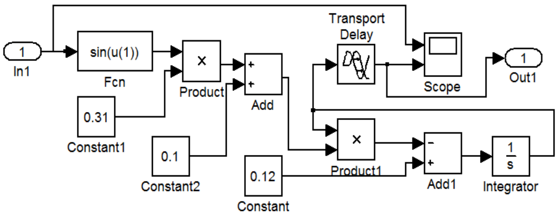

Fig. 6 – Physical model

Figure 7 show the model's unit step response:

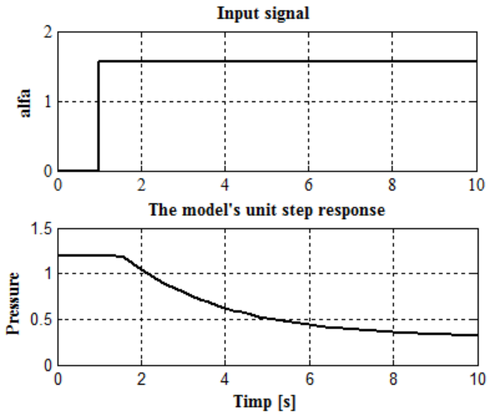

Fig.7 - The model's unit step response

Based on the obtained model the behavior of a PI controller with the following structure was simulated in Simulink

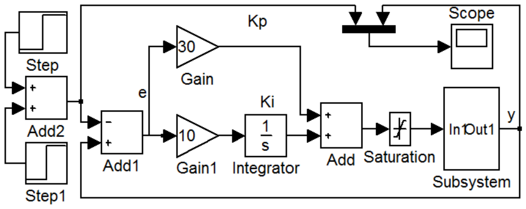

Fig. 8 – Simulated PI controller structure

Graphical representation of output of the physical model based PI controller is shown in fig. 9:

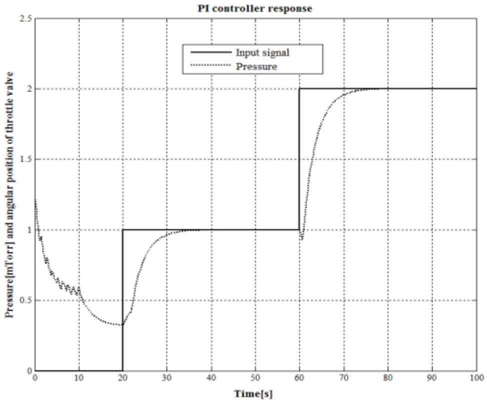

Fig. 9 – The response of PI controller

5.Conclusions

In this paper, based on measurements and physical model, we performed the steps of identifying and modeling pressure control in vacuum chamber. The need of studying a dynamic model was outlined. The final purpose of these studies is the implementation of an automatic pressure control system.

6.Acknowledgements

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