Proceedings of the 7th JFPS International
Symposium on Fluid Power, TOYAMA 2008
September 15-18, 2008

P2-29

SIMULATION OF DYNAMIC CHARACTERISTICS OF AIR GRIPPER BY A NEW BOND-GRAPH METHOD

Yasuo SAKURAI *, Yoshitaka HANEISHI *, Kazuhiro TANAKA**,
Takeshi NAKADA*** and Takehisa KOHDA ****

* Ashikaga Institute of Technology
268-1 Oomaecho, Ashikaga, Tochigi, 326-8558 Japan
(E-mail: ysakurai@ashitech.ac.jp)
** Kyushu Institute of Technology
680-4 Kawazu, Iizuka, Fukuoka 820-0067, Japan
*** Tokyo Denki University
2-1200 Muzai gakuendai, Innzai City, Chiba, 270-1382 Japan
**** Kyoto University
Yoshida-honmachi, Sakyo-ku, Kyoto 606-8501 Japan

ABSTRACT

This paper deals with the simulation of the dynamic characteristics of an air gripper by a new bond-graph method. Recently, pneumatic systems are widely used with food equipments and wrapping ones, etc. However, the design and the improvement of those pneumatic systems take much time because they depend largely on the experience of designers. In order to make them more effective and systematic, it is necessary and important to predict the dynamic behavior of the system beforehand by computer simulation. An air gripper is often used as an actuator in a pneumatic system. However, there are few reports focused on its dynamic characteristic as authors know. In this paper, to obtain a suitable mathematical model for an air gripper and to show the usefulness of the proposed bond-graph method, both experimental and simulation studies are performed. In modeling for pneumatic field, the new bond-graph method is employed, which had been proposed by some of authors. In the bond-graph method, a pneumatic system can be represented by using conventional 1-port C and 1-port R elements.

KEY WORDS

Pneumatics, Air Gripper, Bond-graph method, Dynamic Characteristics, Simulation

NOMENCLATURE

A : area [m^2]
A_e : effective area [m^2]
M : mass of air in a chamber or a volume [kg]
$\dot{m}$: mass flow rate [kg/s]
P : absolute pressure [Pa]
R : gas constant [J/(kg・K)]
T : absolute temperature [K]
t : time [s]
V : volume [m^3]
v : velocity [m/s]
x : displacement [m]
κ : specific heat ratio

Subscripts

A : atmosphere

E : experiment
F : finger
H : head side of an air gripper
P : piston
R : rod side of an air gripper
S : air supply
Si : simulation

INTRODUCTION

Recently, pneumatic systems are widely used with food equipments and wrapping ones, etc. Generally speaking, the design and the improvement of those pneumatic systems take much time because they depend largely on the experience of designers. In order to make them more effective and systematic, it is necessary and important to predict the dynamic behavior of the system beforehand by computer simulation.

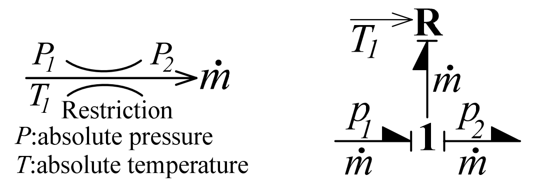
Pneumatic systems have mechanical and pneumatic fields. Pneumatic field has compressible fluid-flow and thermal fields. In constructing the bond-graph model for such a system, true or pseudo bond-graph has so far been employed. Furthermore, in constructing the model for the pneumatic field, two kinds of bonds, which represent both fluid power and thermal power, have been used, and multi-port C and multi-port R elements have been frequently used in the model as well [1-6]. Hence, the resulting bond-graph models are complicated. Then, a new bond-graph method had been proposed [7]. In the bond-graph method, the bond-graph models for pneumatic components are derived by using 1-port C and 1-port R elements. However, the usefulness of the method is not clear because the comparison of the simulated results with the experimental ones has not been shown.

An air gripper is often employed as an actuator in a pneumatic system. However, there are few reports focused on its dynamic characteristic as authors know.

In this study, to obtain a suitable mathematical mode for an air gripper and to confirm the usefulness of the proposed bond-graph method, both experimental and simulation studies are performed. In simulation, Mr.Bond [8] is used, which is a simulation program for bond-graph model.

OUTLINE OF NEW BOND-GRAPH METHOD

In this section, outline of a new bond-graph method [7] is shown, that is, each bond-graph model for restriction, chamber of a pneumatic cylinder and a volume of a pipeline is shown. In constructing the bond-graph model for pneumatic field, pseudo bond-graph is employed, in which effort is absolute pressure and flow is mass flow rate. In mechanical field, true bond-graph is used, in which effort is force and flow is velocity.



(a)Restriction (b)Bond-graph model

Figure 1 Bond-graph model for restriction

Restrictive element

At a restriction illustrated in Fig. 1(a), the continuity equation yields

$$\dot m_1 = \dot m_2 = \dot m \tag{1}$$

where $\dot m_i$ (i=1,2) is the mass flow rate through cross sections 1 and 2 in Fig. 1(a), respectively.

The mass flow rate through the restriction can be expressed by Eq. (2) and (3).

$$0 \le \frac{P_2}{P_1} < 0.528$$

$$\dot m = A_e P_1 \sqrt{\frac{\kappa}{RT_1}\left\{\left(\frac{2}{\kappa+1}\right)^{\frac{\kappa+1}{\kappa-1}}\right\}} \tag{2}$$

$$0.528 \le \frac{P_2}{P_1} \le 1$$

$$\dot m = A_e P_1 \sqrt{\frac{2\kappa}{\kappa-1}\frac{1}{RT_1}\left\{\left(\frac{P_2}{P_1}\right)^{\frac{2}{\kappa}} - \left(\frac{P_2}{P_1}\right)^{\frac{\kappa+1}{\kappa}}\right\}} \tag{3}$$

As can be seen from Eq. (1), flow $\dot m$ is equal at the restriction. And, from Eqs. (2) and (3), flow $\dot m$ is expressed as a function of effort P_1 and P_2. Therefore, the restriction can be represented by 1-junction and an R-element as shown in Fig. 1(b). In order to calculate mass flow rate $\dot m$ based on Eqs. (2) and (3), temperature T_1 is necessary. Therefore, temperature T_1 is inputted to R-element through the active bond which is denoted by full arrow and transmits a signal.

Capacitive elements

At a head-end chamber of a pneumatic cylinder shown in Fig. 2, the heat transfer through a wall is assumed to be neglected to make the bond-graph structure simple. Then, from the first law of thermodynamics, Eq. (4) can be derived.

$$\frac{dP}{dt} = \frac{\kappa}{V}\left(R\dot m T^* - PAv\right) \tag{4}$$

Assuming that T^* and P in the right-hand side of Eq. (4) can be replaced with the values at one time step before

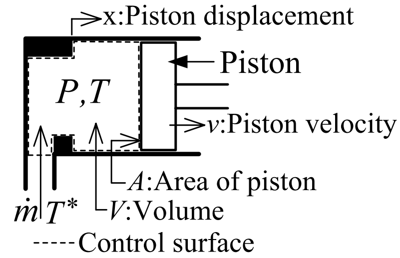


Figure 2 Head-end chamber of pneumatic cylinder

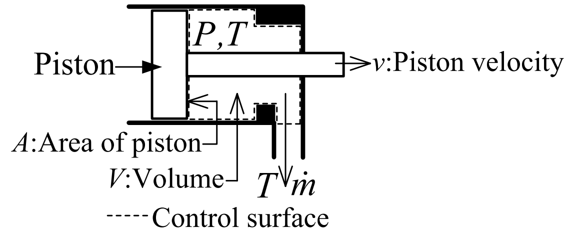


Figure 4 Rod-end chamber of pneumatic cylinder

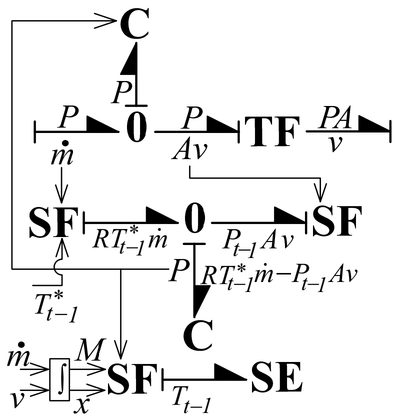


Figure 3 Bond-graph model for head-end chamber of pneumatic cylinder

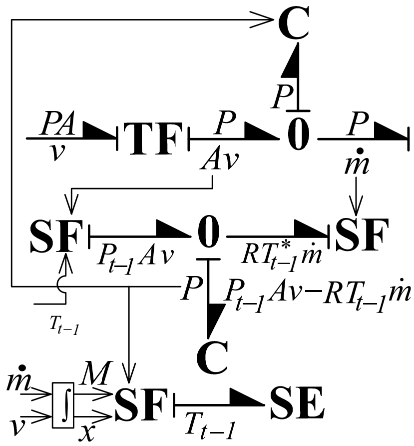


Figure 5 Bond-graph model for rod-end chamber of pneumatic cylinder

the time, we get Eq. (5):

$$P = \frac{\kappa}{V_{H0} + Ax} \int \left(RT^*_{t-1}\,\dot{m} - P_{t-1}\,A\,v \right) dt + P_{H0} \quad (5)$$

where V_{H0} is the head-end chamber dead volume and P_{H0} is the initial pressure at the chamber.

As can be seen from Eq. (5), effort P can be determined by integrating flow $\dot{m}$ and v. And effort P is equal in the head-end chamber of the pneumatic cylinder. Hence, the head-end chamber of pneumatic cylinder shown in Fig. 2 can be modeled by a C-element and 0-junction as shown in Fig. 3. However, in order to calculate effort P from Eq. (5), two SF-elements and a C-element is employed. And then, this C-element is used as a mere integrator. Furthermore, to calculate the temperature of air in the head-end chamber of pneumatic cylinder from Eq. (6), an SF-element and an SE-element are employed as a mere calculator. And then, the flow of the bond between these elements represents the temperature of air in the head-end chamber of pneumatic cylinder at one time step before the time.

$$T = \frac{PV}{MR} \ , \ T_{t-1} = T \quad (6)$$

Similarly, the pressure at the rod-end chamber of a pneumatic cylinder shown in Fig. 4 can be determined by Eq. (7).

$$P = \frac{\kappa}{V_{R0} - Ax} \int \left(-RT_{t-1}\,\dot{m} + P_{t-1}\,A\,v \right) dt + P_{R0} \quad (7)$$

In Eq. (7), V_{R0} is the volume of the rod-end chamber when piston displacement x is equal to 0.

As seen from Eq. (7), effort P can be calculated by integrating flow $\dot{m}$ and v. And effort P is equal in the rod-end chamber of the pneumatic cylinder. Therefore, the rod-end chamber of pneumatic cylinder can be represented as shown in Fig. 5. Then, it should be noted that the temperature of air in the rod-end chamber is used in calculating the pressure of air in the chamber by Eq. (7).

Similarly, the pressure in a pipeline shown in Fig. 6 can be represented by Eq. (8).

$$P = \frac{\kappa R}{V} \int \left\{ (T_1)_{t\text{-}1}\,\dot{m}_1 - (T_2)_{t\text{-}1}\,\dot{m}_2 \right\} dt + P_0 \quad (8)$$

In Eq. (8), P_0 is the initial value of the pressure in the pipeline.

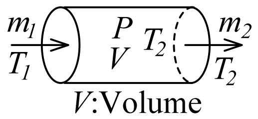


Figure 6 Pipeline

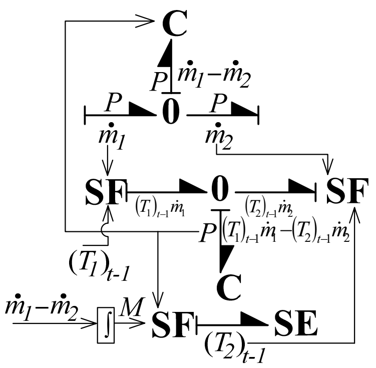


Figure 7 Bond-graph model for pipeline

As seen from Eq.(8), effort P can be calculated by integrating flow $\dot{m}$. And effort P is equal in the pipeline. Therefore, the pipeline can be modeled by bond-graph as shown in Fig. 7. In calculating the pressure of air in the pipeline by Eq. (8), it should be noted that the temperature of air in the pipeline is used.

STRUCTURE OF AIR GRIPPER

The structure of an air gripper is shown in Fig.8. When compressed air flows into the rod end chamber of the air gripper through the port, the levers revolve around the fulcrum and the piston moves downward. And then, the fingers close. In the case where compressed air flows into the head end chamber of the air gripper through the other port, the fingers open. In this study, simulation and experiment are carried out for the case where the fingers close.

BOND-GRAPH MODEL FOR AIR GRIPPER

Figure 9 shows the pneumatic system with an air gripper as an actuator. The compressed air through a solenoid valve flows into the rod end chamber of the air gripper. And then, the fingers close.

By using the bond-graph models for restrictive element and capacitive ones mentioned before, the bond-graph model for pneumatic system in Fig. 9 can be derived. The resulting bond-graph model for the pneumatic system is represented in Fig.10. In constructing the bond-graph model, the followings are assumed:

- At the air supply, both pressure P_S and temperature

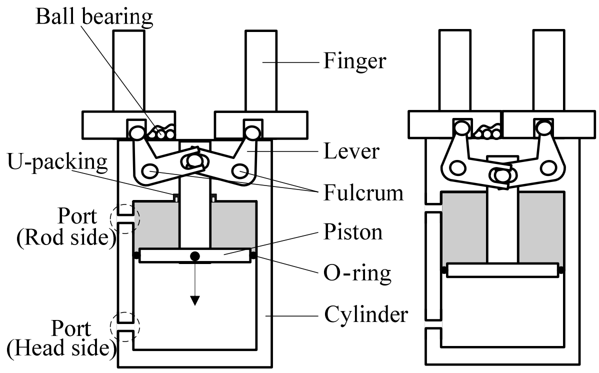


Figure 8 Structure of air gripper

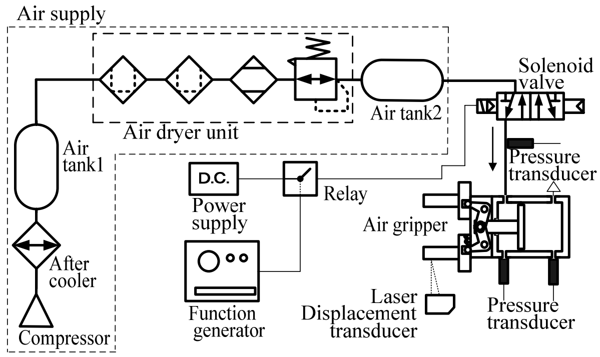


Figure 9 Pneumatic system

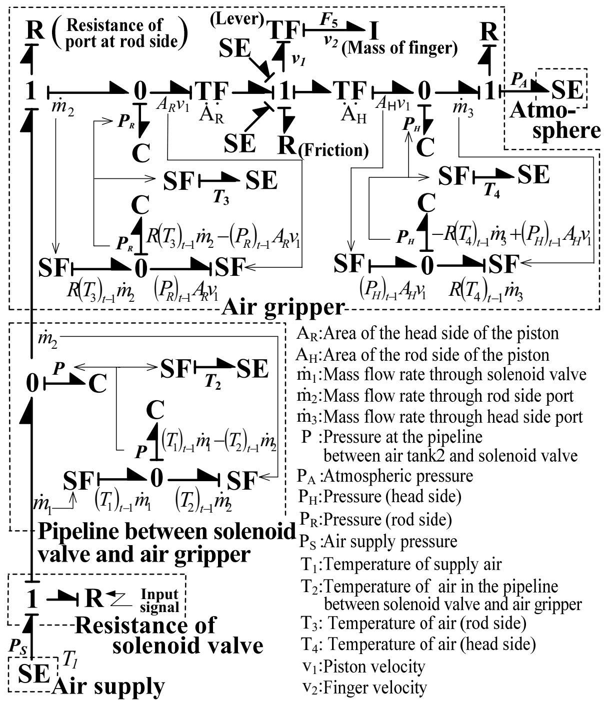


Figure 10 Bond-graph model for pneumatic system

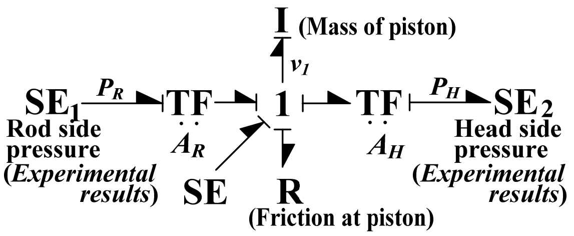


Figure 11 Bong-graph model for air gripper without levers and fingers

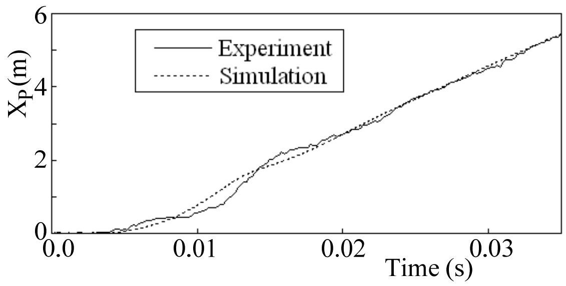


Figure12 Experimental and simulated results for air gripper without levers and fingers

- T_1 of air are constant.
- The pressure and temperature of air upstream of the solenoid valve are equal to those at air supply.
- The heat transfer through the wall is neglected at the pipeline between the solenoid valve and the port at the rod end side of the air gripper, at the rod-end chamber and the head-end one of the air gripper.

SIMULATION AND EXPERIMENT

Prior to simulation, it is necessary to predict the friction of the air gripper. Firstly, to predict the friction at the piston of the air gripper, experiments and simulations were carried out for the air gripper without the finger and the lever. The bond-graph model to predict the friction of the piston is illustrated in Fig.11. Based on the bond-graph model, the simulations were carried out varying supply pressure P_S. Then, the effort of the bond connected to SE_1 was pressure P_R in the rod end chamber obtained by the experiment, and the effort of the bond connected to SE_2 was pressure P_H in the head end chamber obtained by the experiment at the same time. And, by comparing the experimental results and the simulated ones, the friction at the piston was predicted. Figure 12 shows an example of a comparison of piston displacement X_P in both the experiment and the simulation.

Consequently, it becomes clear that its stiction is 5.0N and friction F_D in the case where the piston moves can be approximated by Eq. (9) and coefficient of friction K_D in Eq. (9) is 95.0N・s/m.

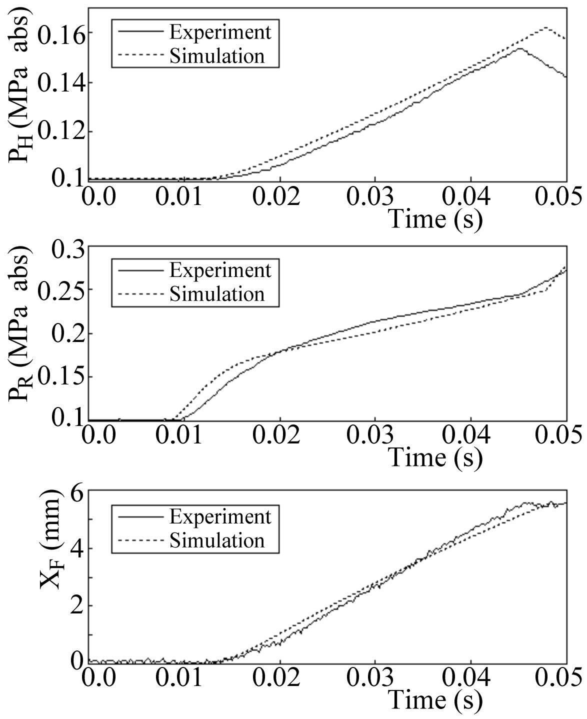


Figure 13 Simulated and experimental results (P_S=0.4MPa abs)

$$F_D = K_D \cdot v \tag{9}$$

Secondly, by using air gripper with the levers and fingers, the above mentioned experiments and simulations were carried out. As a result, the friction characteristics became close to ones in the case where the air gripper without the levers and the fingers was employed. Therefore, it is shown that the friction of the air gripper is mainly determined by the friction at the piston.

By using the predicted friction characteristics and the bond-graph model expressed in Fig.10, the simulations were carried out varying supply pressure P_S. The comparison of the simulated results and experimental ones are shown in Fig.13 and Fig.14. The comparison of time t_E and t_{Si} is shown in Table 1. In this table, time t_E and t_S denote the time until the fingers close in the experiment and the simulation respectively. As seen from Figs. 13 and 14, the simulated results agree with experimental ones. Therefore, the proposed new bond-graph method is proved to be valid and useful for the modeling of a pneumatic system. In addition to it, the bond-graph model for an air gripper proposed in this paper is suitable in the prediction of its dynamic characteristics. And from Table 1, by using this bond-graph model, the time until the fingers close can be predicted within 7.0% error.

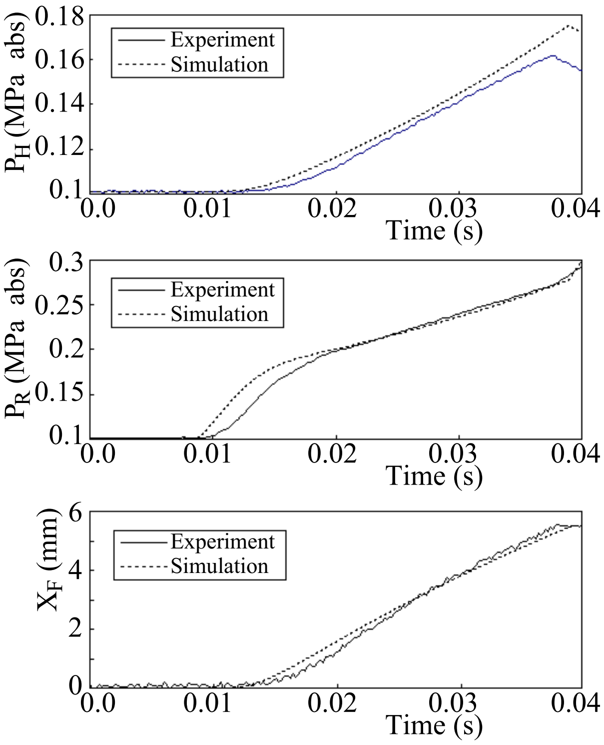


Figure 14 Simulated and experimental results (P_S=0.6MPa abs)

CONCLUSIONS

The bond-graph model for an air gripper is derived by a new bond-graph method. By the use of the bond-graph method, restrictive or capacitive element in pneumatic system can be represented by 1-port R or 1-port C element. To clarify the validity of the bond-graph model for the air gripper and the usefulness of the new bond-graph method, experiments and simulations were carried out.

The simulated results agree with the experimental ones, and the validity of the bond-graph model for the air gripper and the usefulness of the new bond-graph method are shown.

This study has been supported by SMC Co., Ltd.. We would like to thank here for their cooperation.

REFERENCES

1. Rosenberg, R.C. and Karnopp, D.C., Introduction to Physical System Dynamics, McGraw-Hill, 1983.
2. Shoureshi,R. and McLaughlin,K.: Analytical and Experimental Investigation of Flow-Reversible Heat Exchangers Using Temperature-Entropy Bond Graphs, ASME Journal of Dynamic System, Measurement, and Control, 1984, **106**-6, pp.171/175.
3. Shoureshi,R. and McLaughlin,K., Application of Bond Graphs to Thermofluid Processes and Systems, ASME Journal of Dynamic System, Measurement, and Control, 1985, **107**-12, pp.241-245.
4. Thoma, J.U., Simulation by Bondgraphs, Springer-Verlag, 1990.
5. Thoma, J.U. and B. Ould Bouamama, Modelling and Simulation in Thermal and Chemical Engineering, Springer, 2000.
6. Ikeo, S., Zhang, H., Takahashi, K. and Sakurai, Y., Simulation of Pneumatic Systems Using BGSP, Modeling and Simulation, 1994, pp.80/94.
7. Sakurai, Y., Tanaka, T., Nakada, T and Kohda, T, Simulation of the Dynamic Characteristics of a Pneumatic Circuit by OHC-Sim, Proc. of 6th JFPS Symposium on Fluid Power, 2005, pp.346-351.
8. http://sys.tadano.co.jp/frame/frame3_5.html

Table 1 t_S and t_E

P_S (MPa abs)	t_E (ms)	t_S (ms)	$t_E - t_S$ (ms)	$\frac{t_E - t_S}{t_E}$ (%)
0.3	52.8	56.5	3.7	7.0
0.4	45.4	47.8	2.4	5.3
0.5	41.0	42.6	1.6	3.9
0.6	37.8	38.8	1.0	2.7