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

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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

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
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<tbody>
<tr>
<td>A</td>
<td>area</td>
<td>m²</td>
</tr>
<tr>
<td>A_e</td>
<td>effective area</td>
<td>m²</td>
</tr>
<tr>
<td>M</td>
<td>mass of air in a chamber or a volume</td>
<td>kg</td>
</tr>
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<td>m</td>
<td>mass flow rate</td>
<td>kg/s</td>
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<tr>
<td>P</td>
<td>absolute pressure</td>
<td>Pa</td>
</tr>
<tr>
<td>R</td>
<td>gas constant</td>
<td>J/(kg·K)</td>
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<tr>
<td>T</td>
<td>absolute temperature</td>
<td>K</td>
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<tr>
<td>t</td>
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<tr>
<td>V</td>
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<td>v</td>
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<td>x</td>
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<td>m</td>
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<td>κ</td>
<td>specific heat ratio</td>
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Subscripts

<table>
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<tr>
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<tr>
<td>A</td>
<td>atmosphere</td>
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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.
the time, we get Eq. (5):

\[ P = \frac{\kappa}{V_{H0} + Ax} \int \left( RT_{i-1} \dot{m} - P_{i-1} A v \right) dt + P_{H0} \tag{5} \]

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.

\[ T = \frac{PV}{MR}, \quad T_{i-1} = T \tag{6} \]

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

\[ P = \frac{\kappa}{V_{R0} - Ax} \int \left( -RT_{i-1} \dot{m} + P_{i-1} A v \right) dt + P_{R0} \tag{7} \]

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).

\[ P = \frac{\kappa R}{V} \int \left( T_1 \dot{m}_1 - (T_2)_{i-1} \dot{m}_2 \right) dt + P_0 \tag{8} \]

In Eq. (8), \( P_0 \) is the initial value of the pressure in the pipeline.
As seen from Eq.(8), effort $P$ can be calculated by integrating flow $m$. 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 $T_S$ are constant.
- At the air dryer, the relative humidity is constant and the temperature is decreasing.
- At the after cooler, the temperature is constant, and the pressure is decreasing.
- At the compressor, the temperature is constant, and the pressure is increasing.
- At the pressure transducer, pressure is measured.
- At the displacement transducer, the displacement is measured.
- At the power generator, power is measured.
- At the function generator, the signal is transformed.
- At the solenoid valve, the pressure is constant when the solenoid valve is on and the pressure decreases when the solenoid valve is off.

**Figure 10 Bond-graph model for pneumatic system**
$T_1$ 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.

$$F_D = K_D \cdot \dot{v}$$

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 $t_S$ 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.
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.

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REFERENCES