

DEVELOPMENT OF MODEL SELECTION PROGRAM FOR COMPLEX PNEUMATIC CIRCUITS

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ABSTRACT

Pneumatic system is applied in a wide range of industries. There are many kinds of pneumatic circuits that are used in different applied cases, such as transportation, clamp, press, etc. Among those pneumatic circuits, pneumatic circuit with only one cylinder controlled by one valve is primary for application, while branch circuit, which is consisted of multiple cylinders controlled by one valve, and manifold circuit, which is consisted of multiple cylinders controlled by multiple valves, is commonly applied in practices. In this paper, a simulation program for complex pneumatic circuits, especially for branch circuits and manifold circuits, is developed for model selection and characteristic calculation. Firstly, outline and specifications of the simulation program is introduced; secondly, modeling and simulation method of branch circuit and manifold circuit are explained; finally, an example of application is presented to verify the accuracy of the simulation program.

KEY WORDS

Pneumatic System, Branch Circuit, Manifold, Model Selection, Simulation

INTRODUCTION

Pneumatic system is applied to various fields for transportation, clamp, press, and so on. As applications are different, the pneumatic circuits are various. The basic circuit with one cylinder controlled by one valve is the most primary, while the branch circuit, which is consisted of multiple cylinders controlled by one valve, and the manifold circuit, which is consisted of multiple cylinders controlled by multiple valves, are more popular^{1), 2)}. The software named Pneumatic Model Selection Program was developed to support the model selection and characteristic simulation of basic circuit in version 2. And it is enhanced to simulate complex

pneumatic systems such as branch circuits and manifold circuits in the last version.

In the following sections, firstly, outline and guidance of the software version 3 is introduced; then, modeling and simulation method of branch circuit and manifold circuit are introduced; finally, an example of application is presented.

OUTLINE OF PROGRAM

The Pneumatic Model Selection Program Ver.3 can be executed in WindowsNT4.0 and Windows 98/2000/XP. Its CD-ROM version and Web version have been developed at the same time.

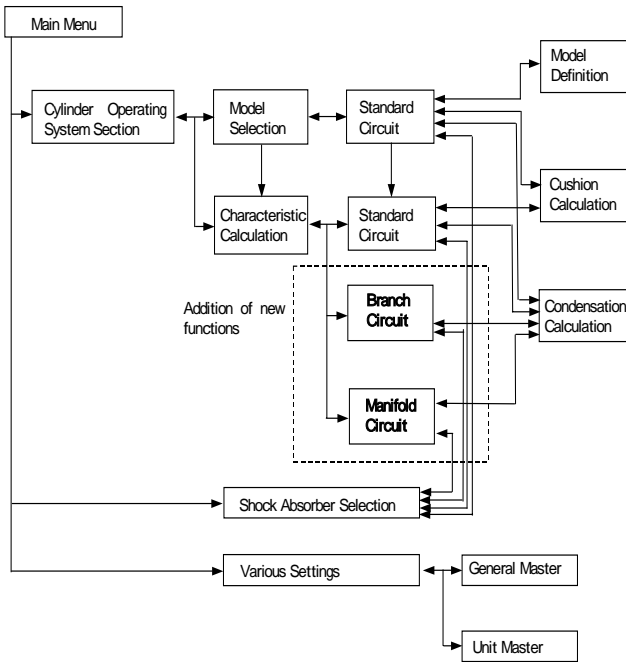


Figure 1 Configuration of Model Selection Program

Figure 1 shows configuration of the Pneumatic Model Selection Program. The software includes three main parts, the model selection for cylinder operating system, the characteristic calculation for cylinder operating system, and the model selection for shock absorber. With the help of the model selection for cylinder operating system, product models with proper size are automatically selected for basic circuits. With the help of the characteristic calculation for cylinder operating system, all dynamic characteristics are simulated for basic circuits, branch circuits and manifold circuits. Furthermore, cushion capacity and condensation probability for circuits can be calculated with the software, too.

CALCULATION SCREENS

Branch Circuit

Input screens of branch circuit are displayed in the figure 2. Total number of multiple cylinders controlled by a valve should not be allowed more than 10 in one branch circuit in the software.

When the “Common” button is clicked, an input screen will be popped up. Supply pressure, ambient temperature, and the model specifications for pipes, valve and silencer can be set in the common circuit input screen, as it is showed in the figure 2 (A).

Clicking the “Individual” button will open another input screen. The model and specifications for cylinder, flow controller and pipe can be set in the individual circuit

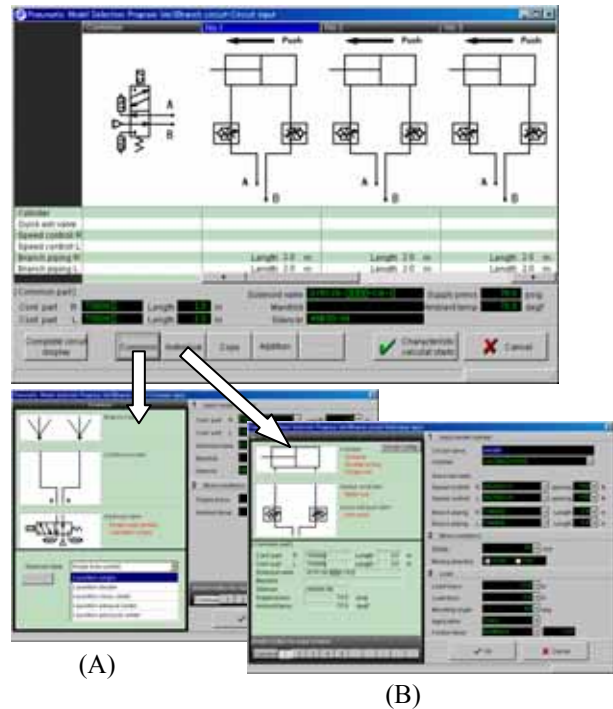


Figure 2 Input screens for branch circuit

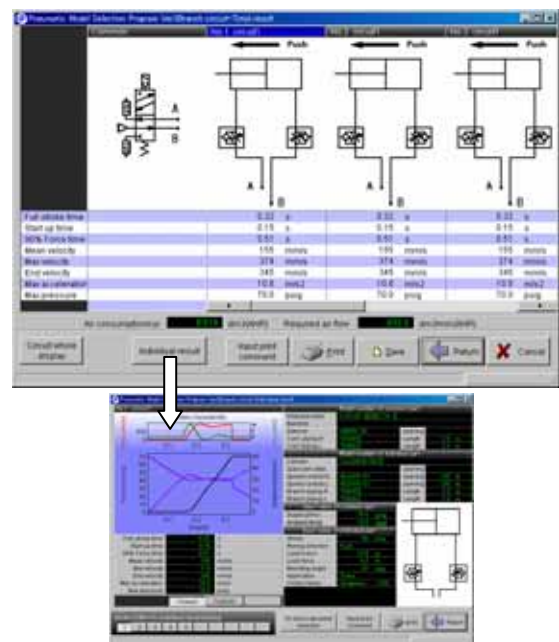


Figure 3 Output screens for branch circuit

input screen, as it is showed in figure2 (B). Cylinders of single action type and double action type are allowed at the same time in branch circuit.

For convenience of circuit design, functions of copy, add, and delete are also included for individual circuits in branch circuit input screen.

After all conditions are input, and the “Calculation” button is clicked, dynamic characteristics of branch circuit will be automatically calculated by simulation. Figure 3 shows output screens for calculation results of branch circuit. Stroke time, start time, final velocity, etc. are displayed for all cylinders in the branch circuit output screen.

Detail results of every cylinder will be showed if the “Individual Result” button is clicked. Cushion capacity can be calculated by clicking the “Cushion” button. And if necessary, proper model of shock absorber can be selected by clicking the “To shock absorber section” button.

Manifold Circuit

Figure 4 shows input screens of the manifold circuit. The maximum number of valves is 20 in one manifold circuit in the software.

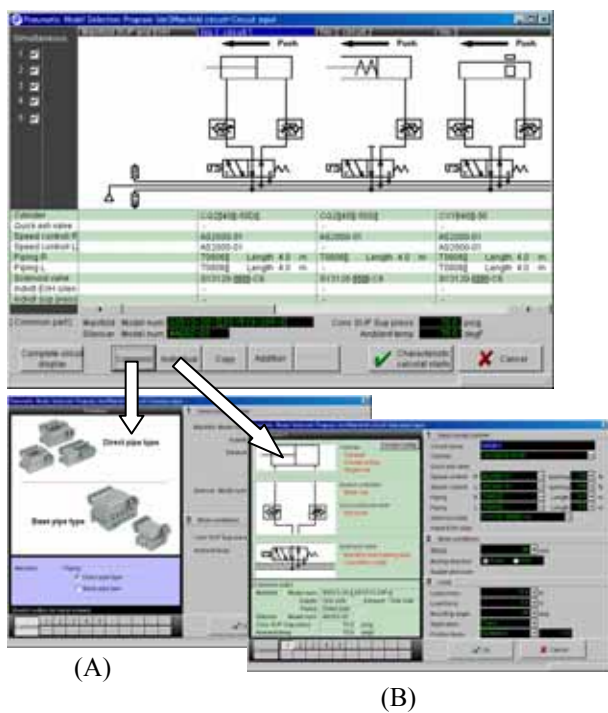


Figure 4 Input screens for manifold circuit

After the “Common” button is clicked, the common circuit input screen will be appearing as it is showed in Figure 4 (A). Supply pressure, ambient temperature, and model specifications for pipes, silencer can be set in this screen. Supply port and exhaust port can be set as one side type or both side type according to the specification of manifold.

After the “Individual” button is clicked, the individual input screen will be opened as it is showed in the figure 4 (B). Model and the specifications for cylinder, valve, flow controller and pipe can be set in this screen. Exhaust ports and supply ports of valves can be set as

common type or individual type according to specifications of valve-manifold unit, after the “Circuit Configuration” button is clicked.

For convenience of circuit design, copy, add, and delete functions are also provided for individual circuits in the input screen of manifold circuit.

In the manifold circuit input screen, individual circuits that are driven simultaneously can be chosen and set before simulation starts.

After all conditions are input, and the “Calculation” button is clicked, dynamic characteristics of manifold circuits will be automatically calculated by simulation.

Figure 5 shows output screens of calculation results of manifold circuit. Stroke time, start time, finally velocity, etc. are displayed for every cylinder in the manifold circuit output screen.

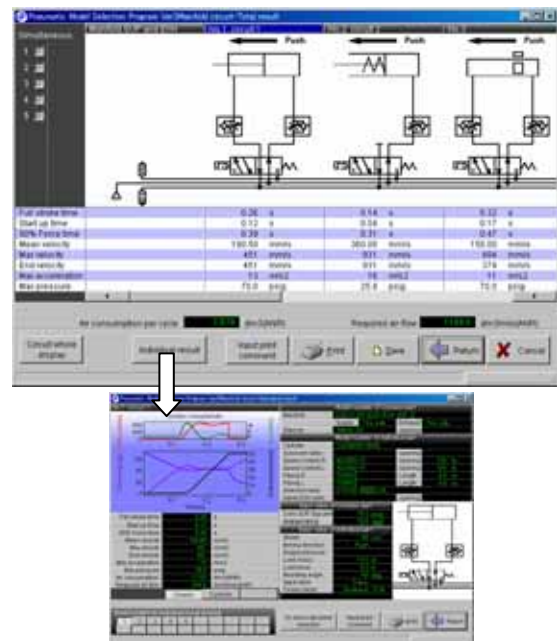


Figure 5 Output screens for manifold circuit

As same as branch circuit, detail results of every cylinder in manifold circuit are showed after the “Individual Result” button is clicked. Cushion capacity can be calculated by clicking the “Cushion” button. And if necessary, proper model of shock absorber can be selected by clicking the “To shock absorber section” button.

MODELS AND EXAMPLES

Modeling

Pipes, cylinders and valves in all kinds of circuits are separately simulated with the distribution pipe model, the cylinder basic equations, and the ISO flow rate

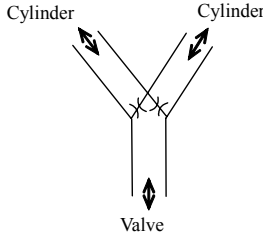


Figure 6 Model of branch circuit

characteristic equations.²⁾ Branch circuit and manifold circuit are simulated with the models described as follows.

Figure 6 shows the model of branch circuit. Considering pressure loss in branch circuit, instead of traditional method of loss rate, a fixed flow conductance is applied to model the resistance effect of branch circuit. Air flow from valve through every branch to all cylinders is considered, but air flow from one branch to the others is neglected in the model.

Choked air flow through branch circuit is calculated with equation (1).

$$G = Cp\rho_0 \sqrt{\frac{T_0}{T}} \quad (1)$$

Where G [g/s] is mass flow rate; C [dm³/(s·bar)] is conductance of branch circuit; p [bar] is absolute pressure of upstream air; $\rho_0=1.185$ [g/dm³] is air density of the standard reference conditions; $T_0=293.15$ [K] is air temperature of the standard reference conditions; and T [K] is upstream air temperature.

Subsonic air flow through branch circuit is calculated with equation (2).

$$G = Cp\rho_0 \sqrt{\frac{T_0}{T}} \sqrt{1 - \left(\frac{p_a - b}{1 - b} \right)^2} \quad (2)$$

Where p_a [bar] is absolute pressure of downstream air; b [-] is critical pressure ratio of branch circuit.

Figure 7 shows the model of manifold circuit. Lumped modeling is applied to inner volume of manifold. Supply volume is treated as a charge chamber, and exhaust volume is treated as a discharge chamber. State change of air is assumed to be isothermal both in charge process and in discharge process.

When equation of air state is applied to discharge chamber, change of air pressure is expressed with equation (3).

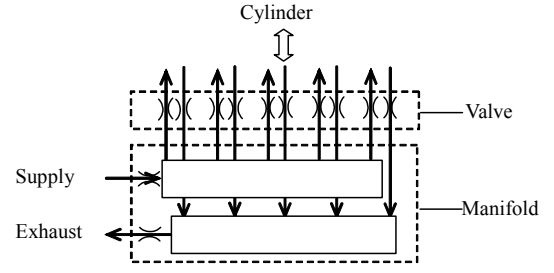


Figure 7 Model of manifold circuit

$$\frac{dp_d}{dt} = \frac{RT_d G_d}{V_d} \quad (3)$$

Where p_d [Pa] is absolute pressure of discharge chamber; t [s] is time passed; $R=287$ [J/(kg·K)] is gas constant; T_d [K] is air temperature of discharge chamber; G_d [kg/s] is mass flow rate of discharging; and V_d [m³] is volume of discharge chamber.

When equation of state is applied to charge chamber, change of air pressure is expressed with equation (4).

$$\frac{dp_u}{dt} = \frac{RT_u G_u}{V_u} \quad (4)$$

Where p_u [Pa] is absolute pressure of charge chamber; T_u [K] is air temperature of charge chamber; G_u [kg/s] is mass flow rate of charging; and V_u [m³] is volume of charge chamber.

Calculation Example

As an example, simulation and experiment results of a branch circuit is presented. It is a pneumatic system with five different cylinders controlled by one valve. The load of every cylinder is 1kg on the top of piston as showed in the figure 8.

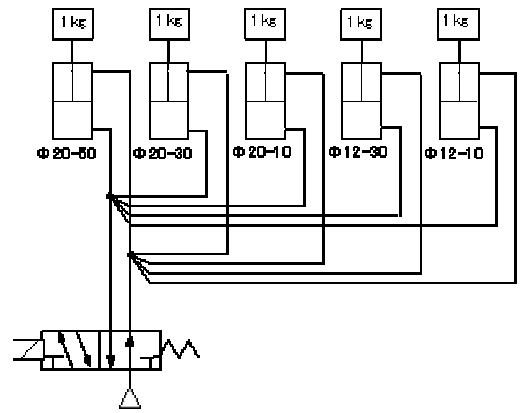


Figure 8 Example of calculation

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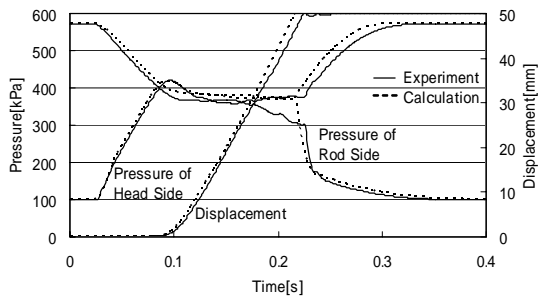


Figure 9 Results of push-out process

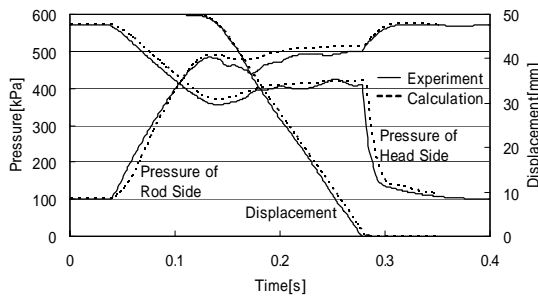


Figure 10 Results of pull-in process

Pressure in rod side chamber and head side chamber of the cylinders, and displacement of the pistons are tested in practical experiments. And the circuit is simulated with the Pneumatic Model Selection Program too, to get all dynamic characteristics.

One of the cylinders in the branch circuit is with 20mm diameter and 50mm stroke. Figure 9 shows the results of push-out process of the cylinder. The simulation results are in close agreement with the experiment results. Figure 10 shows the results of pull-in process of the cylinder. The simulation results are also in close agreement with the experiment results.

CONCLUSION

Firstly, outline and guidance of the Pneumatic Model Selection Program is introduced in this paper. Secondly, modeling and calculation method of branch circuit and manifold circuit is explained. Thirdly, a practical example of branch circuit is presented. Obviously, with the help of the Pneumatic Model Selection Program, design of complex pneumatic system, such as branch circuits and manifold circuits becomes easy and efficient.

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