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AN APPROACH TO ENERGY CONSERVATION IN PNEUMATIC SYSTEMS WITH METER OUT CIRCUIT

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ABSTRACT

Air cylinders have been used with meter out control. In these cases, the outlet pressure of air compressors are set at 0.5~0.7[MPa] for consumption air saving, and so downstream pressure of the actuator is low level, such as nearly atmospheric pressure. For pneumatic energy conservation, it is most important that supplying air use effectively. A lot of small cylinders are worked in automatic factory product systems, and air supply lines are longer between compressor and these cylinders. So, in a plant, energy consumption of pneumatic system is bigger and gets big losses.
In this paper, the authors propose that the exhaust pressure of the cylinder hold middle level (0.2~0.5[MPa]), and so the downstream available for running air blow guns etc. This paper shows the air cylinder dynamics at start and stop, then the parameter are exhaust pressures, cylinder load, supply piping length. Assuming that exhaust flow is used effectively, the proposal method available to prove energy conservation of pneumatic systems. For example, the exhaust pressure setting 0.2[MPa] reduce 15% of pneumatic energy consumption.

KEY WORDS

Eco-System, Cylinder, Meter Out, Modeling

NOMENCLATURE

A : receiving pressure area
a : heat transfer area
c_P : specific heat at constant volume
c_V : specific heat at constant pressure
E : energy
f_F : friction force
G : mass flow rate of air
h : specific enthalpy
M : Mass
α : heat transfer coefficient
m : moving load
p : pressure
Q : inlet flow rte
R : gas constant
T : temperature
t : time
V : volume
x : piston displacement

suffix

1 : source
2 : load
S : supply

INTRODUCTION

In many fields, the concrete reduction in CO2 emissions has been required since the Kyoto Protocol came into effect in February 2005. Japan has not yet solved the assignment of the 6% reduction in CO2 emissions. The situation urges also the field of pneumatic power systems to develop any practical measures for reducing CO2 emissions. Despite its application to a wide variety of use, for example auto-assembly machines, pneumatic power systems are estimated to be less energy-efficient comparing with electric or hydraulic power systems. The estimation is, however, based on its energy-efficiency in a steady operating state and doesn't always apply to intermittent operations.

In this situation, the authors have developed the experimental research for reducing CO_2 emissions in pneumatic cylinders which are the typical operational parts of pneumatic power systems. The research

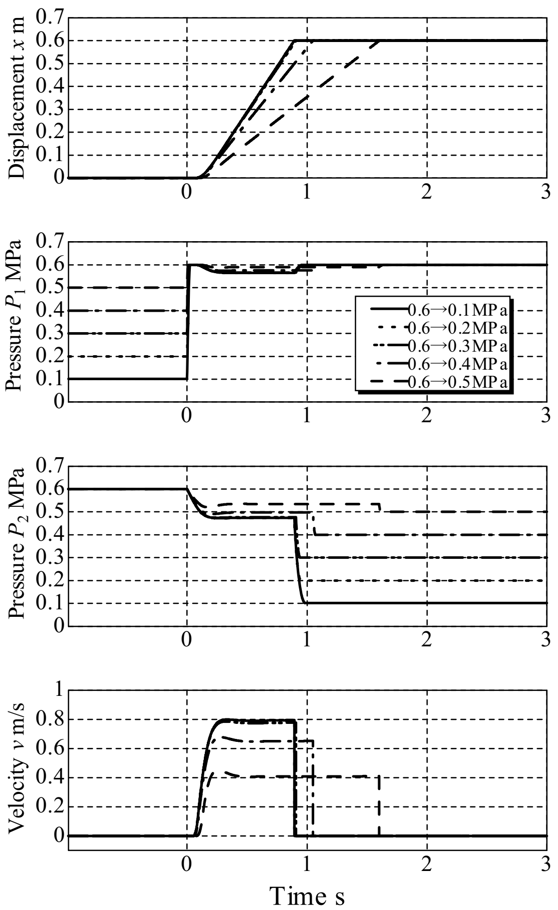

Figure 1 Effects of Exhaust Pressure (Simulation)

proposed the measures to reduce the amount of air consumption in meter-in circuits and showed its effectiveness. Then the measures in meter-out circuits have been considered on the greater use in general. As a method to reduce the amount of air consumption in meter-out circuits, lower air pressure is generally supplied. But this makes bad effects such as the lower sensitivity of response and holding power. Therefore the authors will propose that higher exhaust line pressure than atmospheric pressure should be applied to meter-out circuits to reduce the amount of air consumption as keeping its characteristic. This idea was led by the fact that many plants use their compressed air for air blowing the most and provides efficient use of air supplied from exhaust lines for air blowing.

THE PROPOSED DRIVING METHOD

This proposal comes from the basically unchanged behavior of air cylinders with choked flow on the exhaust side.

As obviously shown in Fig.1, the driving side cylinder pressure is almost unrelated to the exhaust line pressure (i.e. the initial pressure) and the exhaust side cylinder pressure is constant and unrelated to the exhaust line pressure until the piston reaches the end of its stroke.

These show that the cylinder response is almost unrelated to the exhaust lien pressure if choked flow occurs on the exhaust side. This corresponds to the fundamental concept of meter-out circuits in which the stroke speed can be adjusted by supplying compressed air to the driving side cylinder and controlling the exhaust side pressure with speed controller on the exhaust side. From another angle, while meter-in circuits control the amount of supplied energy so that the systems provide energy conservation (reduction of air consumption), meter-out circuits do not directory control the amount of supplied energy so that this method attempts reducing air consumption by the higher exhaust line pressure.

THE OUTLINE OF THE EXPERIMENTAL SETUP

The flow chart of the experimental setup is shown in Fig.2. The air cylinder is set horizontally and drives the load on the cart with the linier bearings. The exhaust

The experiments for this paper assume that the load should give constant force. The load is connected to the rod of the air cylinder with the wire through the pulley. The load direction same with the driving direction is defined as positive. The load direction opposite to the driving direction is defined as negative. The inlet side of the cylinder is called primary. The exhaust side is called secondary. The air tank supplied the air of constant pressure through the pressure regulator gives a virtual exhaust line.

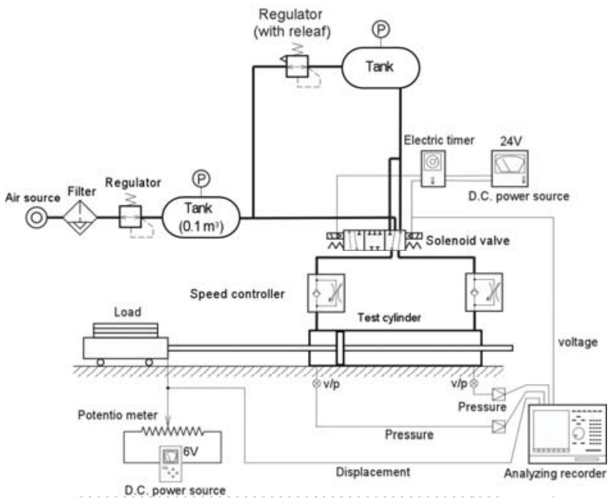

Figure 2 Experimental apparatus

line is represented by the air tank with its inside pressure constant.

The following equation was used for the simulation.

1) Equations of mass conservation

$$\begin{cases} \dfrac{dM_1}{dt} = G_1 \\ \dfrac{dM_2}{dt} = -G_2 \end{cases}$$

2) equations of energy conservation

$$\begin{cases} \dfrac{dE_1}{dt} = G_1 h_s - p_1 \dfrac{dV_1}{dt} + Q_1 \\ \dfrac{dE_2}{dt} = -G_2 h_2 - p_2 \dfrac{dV_2}{dt} + Q_2 \end{cases}$$

3) state equations of ideal gas

$$\begin{cases} p_1 V_1 = M_1 R T_1 \\ p_2 V_2 = M_2 R T_2 \end{cases}$$

4) equation of load mass

$$m\frac{d^2 x}{dt^2} = A(p_1 - p_2) - f_f$$

CONSIDERATION BY THE EXPERIMENTS

THE VALIDITY OF THE SIMULATION

Fig.3 illustrates one of the experimental results. It obviously shows that the response of the cylinder is almost unrelated to the exhaust line pressure at 0.6[MPa] of air pressure on the supplying side and 0.3[MPa] or less of exhaust line pressure. This is reasonable in that choked flow on the exhaust side causes the exhaust line pressure to have no effect. Comparing with the simulation result in Fig.1, the similarity which provides the validity of the simulation model appears.

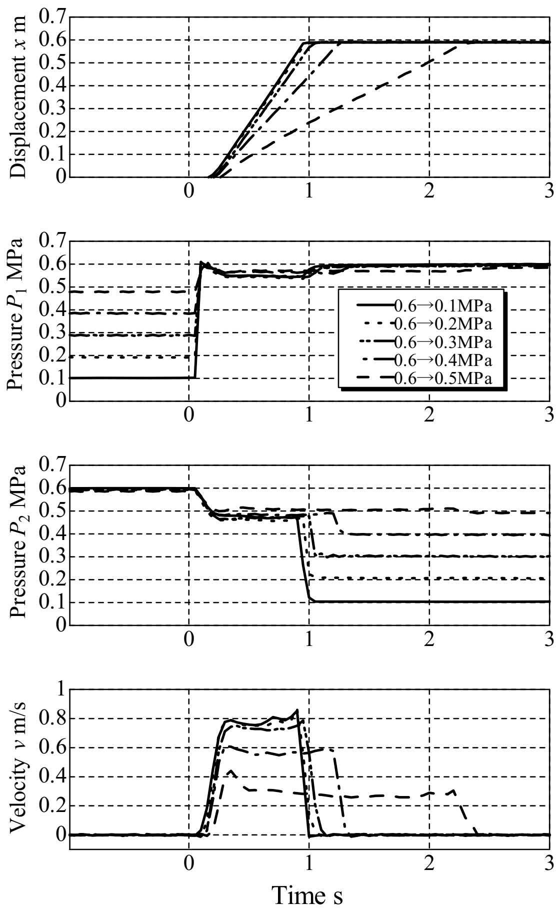

Figure 3 Experimental Results

THE EFFECTS OF THE TUBE VOLUME

Tube volume cannot be ignored for the cylinder volume of smaller pneumatic cylinders. Therefore the higher exhaust line pressure gives more effective reduction in the amount of air consumption for the tube

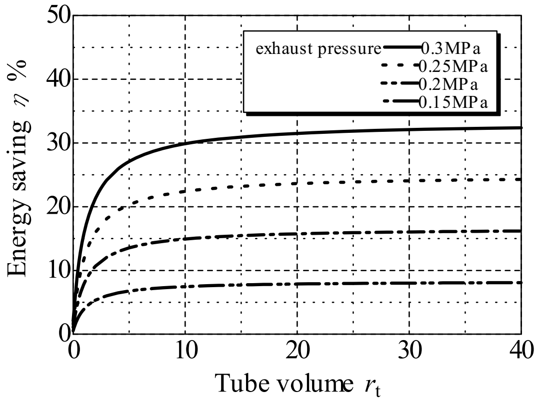

Figure 4 Air Consumption Saving

volume. improves the response slightly and controls the projection speed.

Fig.4 illustrates estimation, the possible amount of reducing air consumption along with tube volume to cylinder volume. As it obviously shows, in the case of larger tube volume for a small pneumatic cylinder, the air consumption reduction rate at 0.6[MPa] of driving pressure and 0.3[MPa] of exhaust line pressure becomes approximately 30%.

Then the effects of exhaust line pressure on response when tube volume cannot be ignored were investigated. One of the experimental results is illustrated in Fig.5.

It is known that a cylinder with its exhaust line pressure set in the range of choked flow can drive as the exhaust line pressure is set at usual atmospheric pressure and that a cylinder can drive normally without choked flow if the cylinder pressure on the exhaust side and the tube pressure give almost the critical pressure ratio. This means, in this case, the higher exhaust line pressure around 0.3[MPa] has almost no effect on the response. Or rather, the higher exhaust line pressure

An increase in the rate of tube volume may also increase the rate of start-up delay to cylinder stroking time. But it is conceivable that higher exhaust line pressure allows tube pressure at a higher level to rise to reduce start-up delay.

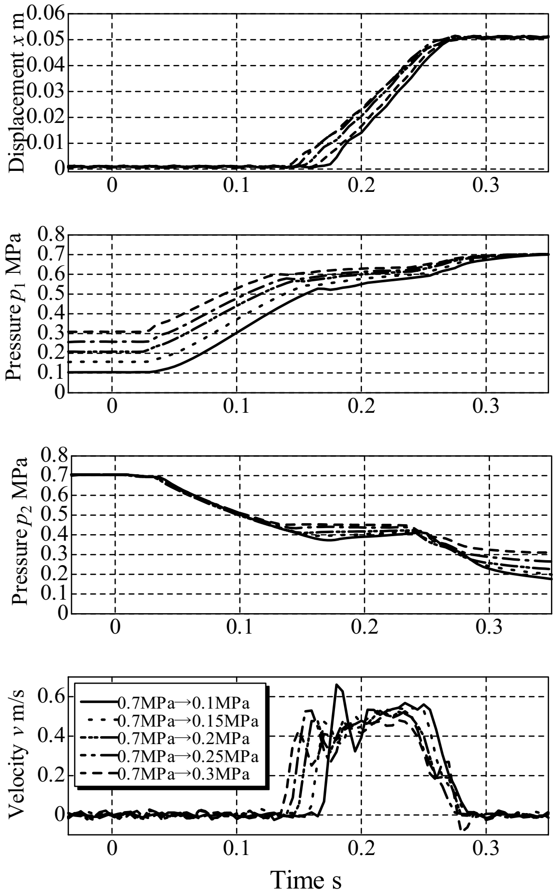

Figure 5 Experimental Results
(Effects of exhaust line pressure at
** % tube volume)

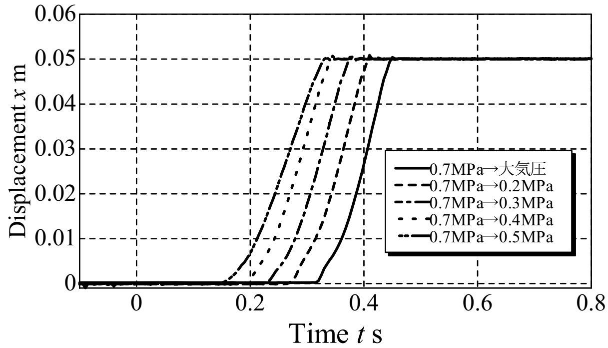

Figure 6 Experimental Results(Tube Volume 20 Times)

THE EFFECTS OF THE LOAD

Fig.7 and Fig.8 illustrate the experimental results. Fig.7 is one of the results when the negative load (the opposite direction to the piston driving direction) was applied. It shows that the higher exhaust line pressure improves the start-up delay. No bad effect of the higher exhaust line pressure can be observed. The improvement is caused by a faster rise in the primary pressure because of the high initial pressure on the primary side (the exhaust line pressure). But the loaded condition requires such higher differential pressure for its start-up that the primary pressure should increase almost up to the supplied pressure and the secondary pressure should decrease. It is considered this decreases the improvement in the start-up delay. The load also requires such higher differential pressure for its driving that the secondary pressure plunges into the range of no choked flow to decrease the driving speed. These appear obviously as the load rate becomes higher.

Fig.8 illustrates the results when the positive load (the same direction with the piston driving direction) was applied. This shows the improvement in the start-up delay and a rise of the secondary pressure. The differential pressure required for its start-up becomes lower because of the force toward the piston driving direction added by the load and can be reached faster because of the high initial pressure on the primary side (the exhaust line pressure). These improve the start-up delay. In addition, the secondary air is compressed so that the pressure becomes higher to give choked flow even in the range of the exhaust line pressure without choked flow normally.

These give a stable drive. That is to say, higher exhaust line pressure makes no bad effects on driving maximum value tends to be lower as exhaust line

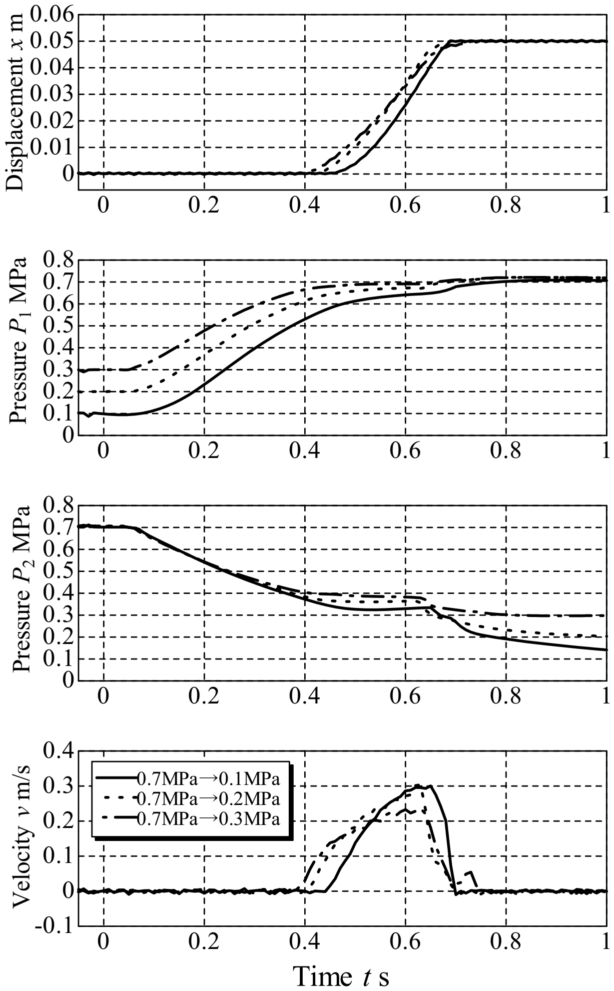

Figure 7 Experimental Results (Load factor -20%)

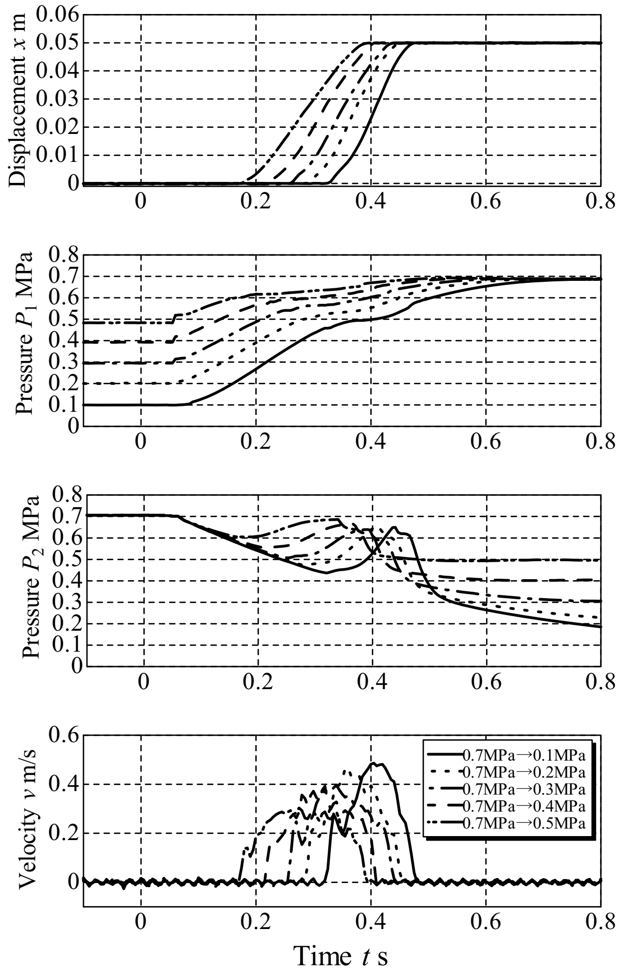

Figure 8 Experimental Results (Load factor +20%)

and improves start-up delay. Focusing on speed, a pressure becomes higher. As described above, however, start-up delay can be reduced to improve the immediacy of response.

In the condition of actual use, the backward driving of reciprocation is typically without load. For a comprehensive driving-efficiency, the use in the range of choked flow without load is recommended.

Then the experiment on the effect of the load rate with the exhaust line pressure constant was made. Fig.9 illustrates one of the results at 0.2[MPa] of exhaust line pressure. No bad effects of the higher load rate on its driving can be observed. In the result, the load adds the force toward the piston driving direction to improve the response. In addition, no remarkable projection with the higher load rate can be observed. The secondary pressure increases greatly as the load rate becomes higher.

CONCLUSIONS

This paper examined the measures to reduce the amount of air consumption in meter-out circuits with higher exhaust line pressure from the viewpoint of the effect of tube volume and driving load. It was shown the method improves the immediacy of response (caused by higher initial cylinder pressure on the driving side) and reduces the amount of air consumption as long as the condition of choked flow and lower maximum driving force are noted. It was proved that while the characteristic of the method depends on the load direction, it improves the immediacy of response in the both directions and can be applied to actual use even if the effect of load is considered.

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