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Experimental Study on Cushioning Characteristics of Pneumatic Cylinder with Meter-In/Meter-Out Control System

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ABSTRACT

Pneumatic cylinder is widely used for mechanical handling systems. Often, the impact occurs at the both ends points of pneumatic cylinder and generates the destructive shock with in the structural operating members of the machine or equipment. To reduce the damage of system, therefore, shock absorbing devices are required. Cushioning of pneumatic cylinders at one or both ends of piston stroke is used to reduce the shock and vibration. The cylinder body have to withstand under conditions of high velocity and load. In this research pneumatic cushioning cylinder moving tests have been conducted for different load mass and supply pressure. The velocity of pneumatic cylinder actuation system which is set vertically with multiple orifice cushion sleeve is controled with the meter-in/out control system. This study examines the dynamic characteristics of pneumatic cylinder which are used as cushion devices. It turns out that the cushion pressure is mainly a function of the external load rather than the supply pressure. The cushion region characteristics was also revealed in the meter-in control system.

Keywords: Pneumatic cushioning cylinder, Meter-in/meter-out control system, Shock and vibration, Shock absorbing devices, Multiple orifice cushion sleeve

1. Introduction

Application of the pneumatic cushioning cylinder, as a component of the automation system, to the general industry, including the simple insertion and removal process, the assembly process, etc. shows a tendency to be rapidly increased.

This tendency results from the point that because the pneumatic cushioning cylinder uses the compressed air as a working fluid, it is cleaner and less expensive than a hydraulic cylinder and further it has characteristics of a higher load and a higher respondence than an electric cylinder. Also, it can be said that this tendency is promoted by improvement in controllability as brought about by the recent rapid advancement of technologies relating to computers, electricity and electronics.

The pneumatic control system largely comprises the compressed air generation system, the lubrication, impurity removal and pressure adjustment system, various control valves controlling velocity, force and direction, tubes and fittings and the cylinder which is in the final linear motion. And it is important to identify correctly characteristics of the pneumatic cushioning cylinder acting as a final actuator out of these components in improving controllability and productivity through the optimum design. When the pneumatic cylinder is in a linear motion, an impact force is generated by the inertial energy in the final working position so that the end cap gets to be broken up. This causes a problem in the system reliability.

Therefore, a shock-absorber is fixed to the final working position in order to prevent any damage resulting from such impact force and vibration as generated by a high working pressure and a high external load.

Meanwhile, many studies have been conducted on the pneumatic cushioning cylinder having an orifice fluid resistance structure and a multiple orifice cushion sleeve installed therein; Kagawa(1) conducted a study on characteristics of temperature variation in the meter-out control system. Wang(2), Adam(3) et al. conducted a study on simulation relating to characteristics of the pneumatic system. Parker(4) conducted a study on calculation of the impact force of the shock absorber fixed to the pneumatic cylinder. In addition, Otis(5), Qiao Yun(6), Hundal(7), Romiti(8), Horlock(9), Anderson(10), et al. ever conducted studies on the cylinder system, but they have never conducted an in-depth study on the cushion area thereof.

Therefore, this study is to identify any change in the cushion pressure and the cushion stroke time of the cushion area through the experiment to be conducted on the meter-in control system and the meter-out control system respectively as the supply pressure and the external load are being varied, wherein only the meter-in control system and the meter-out control system are to be used respectively as the velocity control method and only the cylinder in a vertical downward motion is to be the experimental one in order to interpret any change in the dynamic behavioral characteristics of the cushioning cylinder having a multiple orifice cushion sleeve installed therein, which has been researched and developed by Kim, et al.(11,12).

A pressure sensor, a force sensor, a position sensor, a velocity sensor and an acceleration sensor were fixed to the cylinder, the experimental subject in order to measure its physical quantity. Data measurement was made by opening and closing valves through the digital input/output ports of the analog-digital converter by the computer keyboard, and at this time, 2,000 data samples per second per one channel were collected by using the analog-digital converter to ensure accuracy of the experiment. As a result, it has been identified that any change in the cushioning characteristics was affected by the external load, and further that the system using the meter-out control was stable and any variation in the velocity, the acceleration and the cushion pressure of the cushion area was unstable in the system using the meter-in control.

2. Experimental Apparatus and Method

2.1 Experimental Apparatus

Fig. 1 is a schematic of the internal structure of the pneumatic cushioning cylinder, the experimental subject in this study. Wherein, P1 and T1 represent respectively the air pressure and the air temperature in the supply side and the exhaust side. Pc1 and Pc2 represent the cushion pressure. Fig. 2 is a photograph of the multiple orifice cushion sleeve installed inside the cushioning cylinder. And, Fig. 3 is a schematic of the experimental apparatus. Table 1 shows specifications of the cylinder, the experimental subject, wherein the 10 (5) mm diameter of the flow control valve means the diameter of the supplying pipe or the exhaust pipe in the meter-in control circuit or the meter-out control circuit. That is to say, in the meter-in circuit, the diameter of the supplying pipe is 5 mm and that of the exhaust pipe is 10 mm in the meter-in circuit, while vice versa in the meter-out circuit. Table 2 shows specifications of the measuring equipments which are components the experimental apparatus.

The experimental apparatus used in this study largely comprised the test mechanism section, the compressed air supplying section, the data measuring system using various sensors and the compressed air supply control system.

As shown in Fig. 3, the test mechanism section was designed and manufactured so that the external load could be variably mounted over the top part of the cylinder, the test subject, having the cushioning device installed therein, and the linear bearing was used to minimize friction therein. A position sensor, a velocity sensor and an acceleration sensor, a thermocouple for measuring temperature, a strain gauge-type pressure sensor, a tension/compression load cell and a turbine-type flow meter for measuring a flow rate were installed in various elements of the test subject. The test mechanism was designed so that it could be adjusted horizontally, vertically and to any wanted angle.

The compressed air supply section comprised an air compressor, a lubricating device, an impurity removal and pressure adjusting device, a flow control valve, a pressure control valve, a direction control valve, tubes and fittings. The data acquisition and control system comprised a computer, a data measurement and control card and a printer, and Borland C++ was used therein.

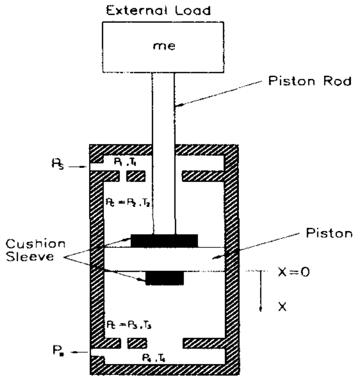


Fig. 1 Schematic of a vertically mounted double acting pneumatic cushioning cylinder.

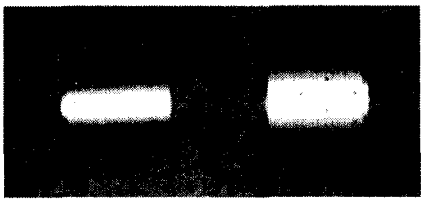


Fig. 2 Photograph of multiple orifice cushion sleeve.

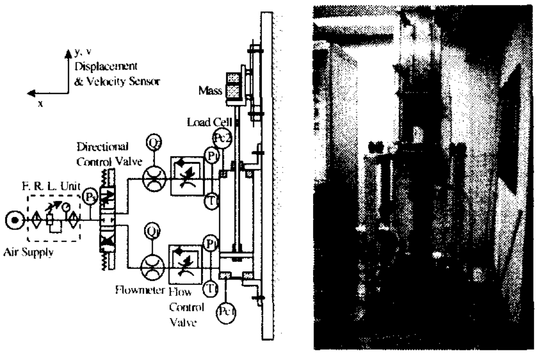
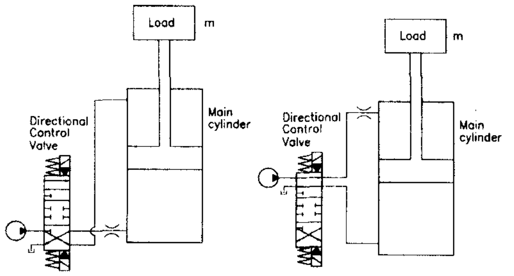


Fig. 3 Schematic diagram of experimental apparatus.



(a) (b)

Fig. 4 Velocity control system of pneumatic cylinder.(a)Meter-out control circuit (b) Meter-in control circuit

Table 1 Specifications of pneumatic cushioning cylinder.

Piston Diameter	Piston Rod Diameter	Stroke	Cushion Diameter	Cushion Length
φ 80mm	φ 25mm	500mm	φ 20mm	28mm
Orifice Diameter	Flow Control Valve Dia.	Directional Control Valve Dia.	Pipe Dia.	Pipe Length
φ 3mm	φ 10(5)mm	φ 14mm	φ 12mm	1000mm

Table 2 Specifications of experimental apparatus.

Items	Pressure Sensor	LVDT Sensor	Load Cell
Specification	.Straingage .0-500psi .0.05% F.S. .0-10volt	.Magnet .0-650mm .0.005% .0.02mm .0-10volt	.Compression &Tension .0-2000lbf .0.1% .0-10volt
Maker	Digitec	Tempsonic	Transducer Technique
Temp. Sensor	Flowmeter	A/D Converter	Amplifier
.T-type thermocouple . φ 0.002mm	.Turbine .Pmax.=10 bar .18-1800l/min .1-5volt	.12[illegible] .100KHz A/D16ch. .D/I,O2ch.	.10KHz,0.2% Gain 1000 .Nonlinearity 0.0%
OMEGA	Sponsler	Adventech	Calex

The velocity control methods used in this experiment were the meter-in control system and the meter-out control system as shown in Fig. 4.

2.2. Experiment Method

Before commencing to conduct the experiment, a calibration experiment[13,14] was conducted on each sensor to ensure correct measurement of any physical quantity. In case of the pressure sensor, the calibration experiment was conducted with the digital pressure sensor being fixed to the same position as the ultra-precision analog pressure gauge and by comparing the analog gauge graduation value with the voltage value of the digital sensor. In case of the position sensor and the velocity sensor, the calibration experiment was conducted by comparing the graduation value of the vernier caliper with the voltage value of the magnetic sensor. In case of the load sensor, the calibration experiment was conducted by comparing the already-known weight of the processed specimen with the voltage of the load cell upon putting the processed specimen on the top of the load cell after the specimen was processed and its weight was measured on a scale. And in case of the temperature sensor, the calibration experiment was conducted by comparing graduation value of the mercury thermometer with the voltage of the thermocouple after the mercury thermometer and the thermocouple were put in ice at the same time.

Then, the experiment was conducted. The solenoid valve was driven by sending 5-volt trigger signals to the relay, using a 100kHz PCL I/O card, and at the same time as the valve commenced to be opened and closed by the computer keyboard control method, the data were acquired through the A/D converter, wherein the method that the data were temporarily stored in RAM and then printed out later was adopted. At this time, 2,000 data samples per second per one channel were collected by using the analog-digital converter to ensure accuracy of the experiment, and about 200 data samples were used for printing out a graph. The experiment was conducted on the meter-in control system and the meter-out control system respectively as the external load and the supply pressure were being varied, wherein only the cylinder in a vertical downward motion was made to be the experimental subject in order to interpret any change in the cushion pressure and the cushion stroke, the characteristic factors of the cushion area depending upon any external condition. That is to say, any changes in position, velocity, acceleration, force and pressure were measured as the external load was being increased to 40 kg, 70 kg and 100 kg respectively at the respective constant supply pressure of 4 bar, 5 bar and 6 bar, and as the supply pressure was being increased to 4 bar, 5 bar and 6 bar respectively at the respective constant external load of 40 kg, 70 kg and 10 kg. All these experiments were conducted under the initial test condition to have lifted the piston rod in the vertical upward direction to the full extent, and data from each sensor were inputted to the computer through the amplification process and the filtering process.

3. Experimental Results and Discussion

Table 3 is a comparison table of the characteristic data between the meter-in control system and the meter-out control system, and Table 4 shows the velocity control characteristics of the meter-in control system and the meter-out system respectively. Fig. 5 shows the characteristics of the installed cushioning cylinder, the test subject, when it was in the vertical downward motion when the supply pressure was 6 bar and the external load was 100 kg in the meter-in control circuit. Fig. 6 shows the result of the experiment conducted on the meter-out control circuit under the same test condition as in Fig. 5. Therefore, with the experimental results, we are to discuss the respective characteristics of the meter-in control circuit, the meter-out control circuit and the meter-in/out control circuit separately.

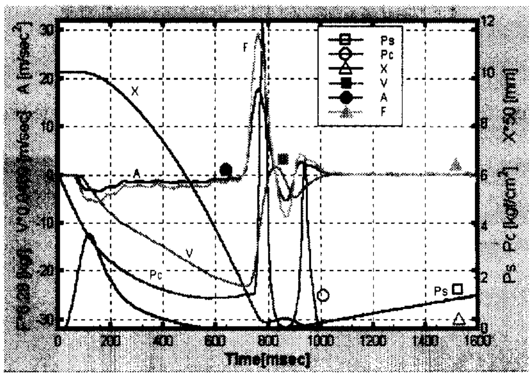


Fig. 5 Experimental results of pneumatic cylinder with meter in control circuit.

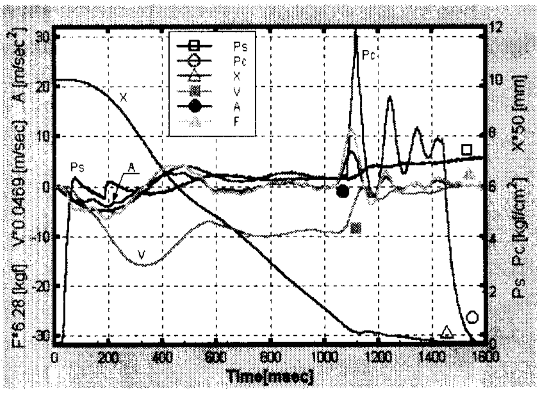


Fig. 6 Experimental results of pneumatic cylinder with meter out control circuit.

Table 3 Comparison of data for velocity control system ; operating condition, load mass 100kg, supply pressure 6bar.

Items	Velocity Control Method	
	Meter In Control circuit	Meter Out Control circuit
Supply Pressure(bar)	6	6
Flow Control Valve Dia.(mm)	φ 5/ φ 10	φ 10/ φ 5
Mean Velocity(m/s)	0.6	0.4
Maximum Velocity(m/s)	1.1	0.7
Cushion Peak Pressure(bar)	12.5	12.0
Cushion Stroke Time(sec)	0.26	0.4
Total Stroke Time(sec)	1.0	1.6
Maximum Acceleration(m/s2)	17.5	7.0
Maximum Load(kg)	175	70
Internal Pressure(bar)	1.8	6.0

Table 4 Comparison of characteristics for velocity control system.

Items	Velocity Control Method	
	Meter In Control circuit	Meter Out Control circuit
Valve On-Off Time	independ on effective area	depend on effective area
Total Stroke Time	depend on load	independ on load
Final Velocity	rapidly down	normally down
Internal Pressure	almost atmosphere	almost equal to supply pressure
Cushion Capacity	bad	good

3.1 In Case of the Meter-In Control System

Fig. 7 shows the result of the experiment conducted on the wave form of the cushion pressure when the supply pressure was increased to 4 bar, 5 bar and 6 bar respectively with the external load being kept constant at 100 kg. Fig. 8 shows the result of measuring the position, where the largest cushion pressure, the cushion stroke time and the total stroke time were found to be 12.5 bar, 0.26 seconds and 1.0 respectively and these values were nearly constant. This means that the cushion area is little affected by any increase in the supply pressure. Fig. 9 and Fig. 10 show the experimental values obtained by conducting each experiment on the wave form of the cushion pressure and the position when the external load was increased to 40 kg, 70 kg and 100 kg respectively with the supply pressure being kept constant at 6 bar. As the external load was increased, the largest cushion pressure was rapidly increased to 4,5 bar, 10.5 bar and 12.5 bar respectively, the cushion stroke time was decreased to 0.3 second, 0.28 second and 0.26 second respectively and the total stroke time was decreased to 1.3 second, 1.1 second and 1.0 second respectively. It was, therefore, found that the external load was a parameter that should be considered in the control and design process because it gave a dominant impact on the cushion area. And it was found that the cushion stroke time was dominantly affected by the dimensions of the cushion sleeve, say, the geometrical effect, and that it had no relation with the external load and the supply pressure, which were external effects.

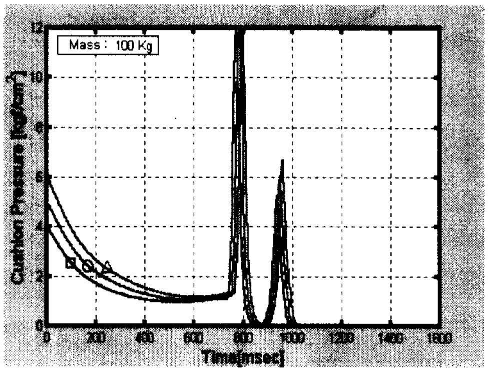


Fig. 7 Cushion pressure of different supply pressures for load mass 100kg.

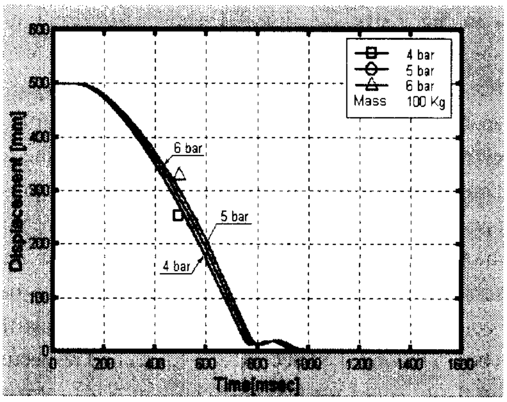


Fig. 8 Displacement of different supply pressures for load mass 100kg.

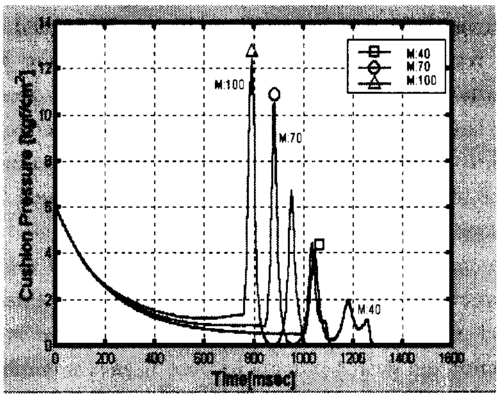


Fig. 9 Cushion pressure of different load masses for supply pressure 6bar.

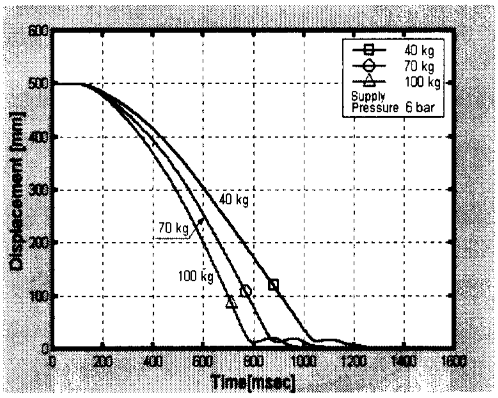


Fig. 10 Displacement of different load masses for supply pressure 6bar.

3.2 In Case of the Meter-Out Control System

Each experiment was conducted in the same manner as in the above 3.1. Fig. 11 shows the result of the experiment conducted on the wave form of the cushion pressure when the supply pressure was increased to 4 bar, 5 bar and 6 bar respectively with the external load being kept constant at 100 kg. Fig. 12 shows the result of measuring the position, and the largest cushion pressure appeared to be 8 bar, 10 bar and 12 bar respectively, which were twice as high as the respective supply pressure. The cushion stroke time was found to be 0.4 second identically, and the total stroke time was found to be 1.5 second, 1.55 second and 1.6 second respectively, and these values were almost constant. This means that the cushion area is little affected by any increase of the supply pressure. Fig. 13 and Fig. 14 show the experimental values obtained by conducting each experiment on the wave form of the cushion pressure and the position when the external load was increased to 40 kg, 70 kg and 100 kg respectively with the supply pressure being kept constant at 6 bar. As the external load was increased, the largest cushion pressure was rapidly increased to 7.8 bar, 9.2 bar and 12.0 bar respectively, the cushion stroke time was 0.4 second almost identically and the total stroke time was decreased to 1.7 second, 1.62 second and 1.6 second respectively. It was, therefore, identified that the external load gave a great impact on any change in the cushion pressure of the cushion area, and that since the total stroke time was almost constant, it was a considerably good control method in view of controlling.

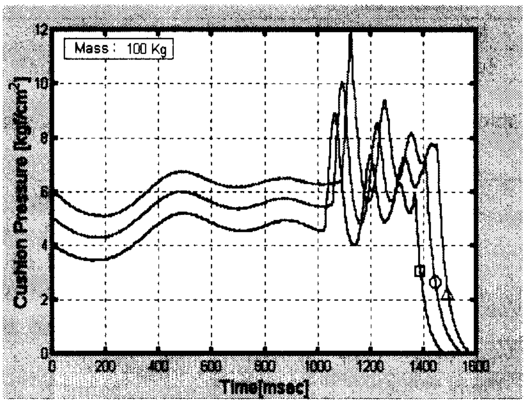


Fig. 11 Cushion pressure of different supply pressures for load mass 100kg.

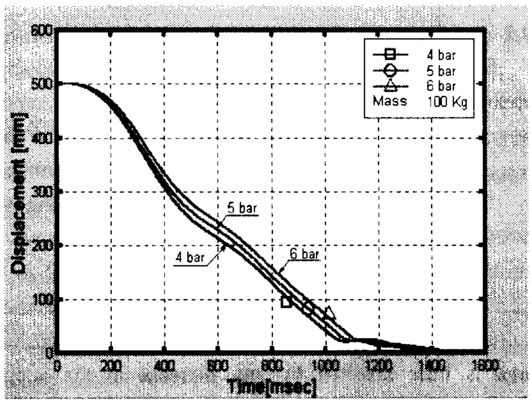


Fig. 12 Displacement of different supply pressure for load mass 100kg.

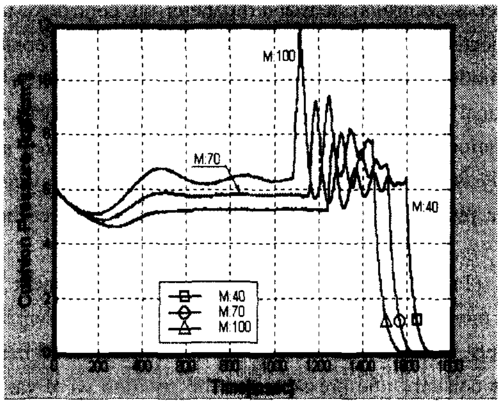


Fig. 13 Cushion pressure of different load mass for supply pressure 6bar.

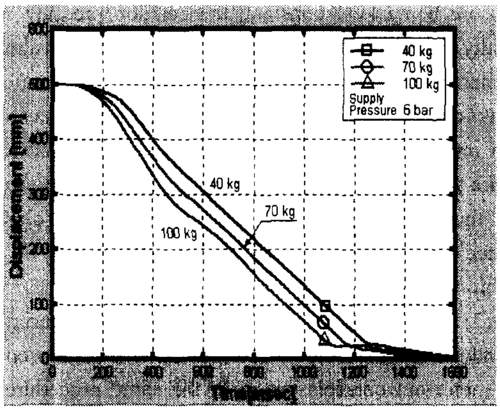


Fig. 14 Displacement of different load mass for supply pressure 6bar.

3.3 Interpretation of Characteristics of Meter-In/Out Control Systems

As described in the above 3.1 and 3.2, the characteristics, which were considerably discriminated depending upon two velocity control methods, were ever identified. The graphs as shown in Fig. 15 to Fig. 20 are to compare the characteristics between the meter-in control system and the meter-out control system, which represent the respective values of the supply pressure, the position, the velocity, the acceleration, the force and the cushion pressure when the supply pressure is 6 bar and the external load is 100 kg. The meter-in control system's respondence is fast since no internal pressure exists in the cylinder, but the stroke time is greatly varied depending upon the external condition, which causes a considerable difficulty in the control aspect. On the other hand, the meter-out control system is so superior in the system stability and the cushioning capability that it can ensure maximization of efficiency and reliability. Furthermore, it is also superior in the controllability. It is, therefore, adopted in most control systems.

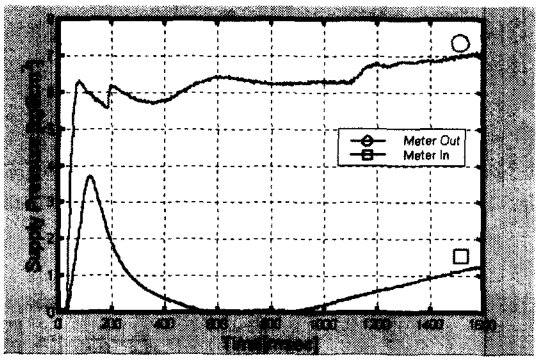


Fig. 15 Comparison of the supply pressure for different velocity control system.

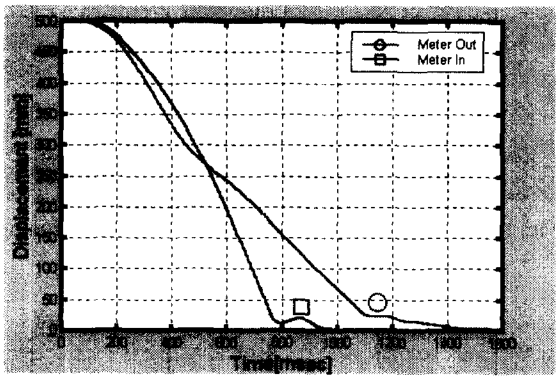


Fig. 16 Comparison of the displacement for different velocity control system.

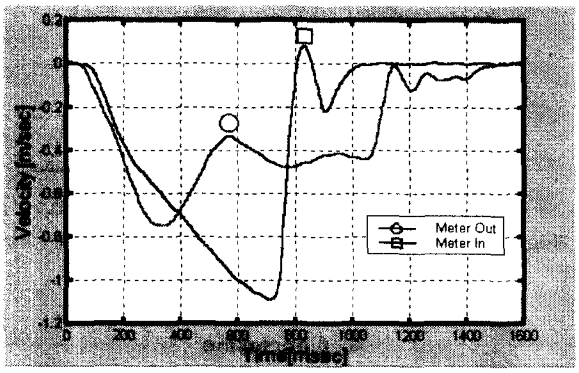


Fig. 17 Comparison of the velocity for different velocity control system.

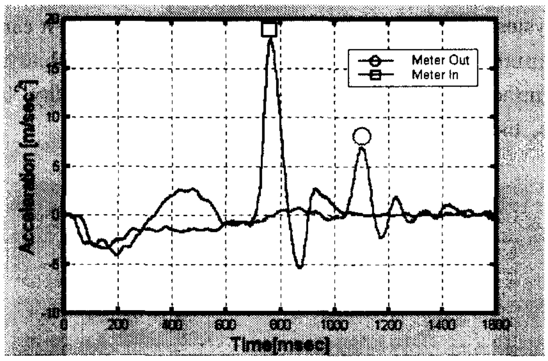


Fig. 18 Comparison of the acceleration for different velocity control system.

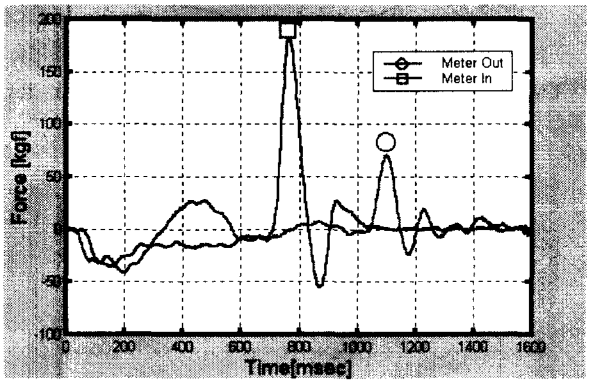


Fig. 19 Comparison of the load force for different velocity control system.

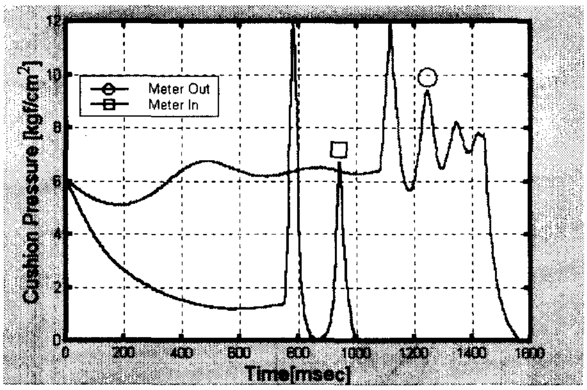


Fig. 20 Comparison of the cushion pressure for different velocity control system.

4. Conclusion

In this study, the experiment was conducted on the meter-in control system and the meter-out control system respectively, which represent two velocity control methods while the pneumatic cushion cylinder is in the vertical downward motion, focusing on analysis of variation in the characteristics of the cushion area and analysis of the characteristics of each control system. As a result, the following conclusion has been reached:

(1) The results obtained from the experiment on the meter-in control system are as follows: When the supply pressure was varied with the external load being kept constant, the pressure and the position were varied almost constantly in the cushion area. On the other hand, when the external load was increased with the supply pressure being kept constant, the cushion pressure was rapidly increased, but the cushion stroke time was almost constant and the total response time was fast. Therefore, it has been identified that the characteristics of the cushion area mean a function of the external load, the cushion stroke time depends on the length of the cushion sleeve and the wave form of the cushion pressure is closely related with distribution of the multiple orifice of the cushion sleeve.

(2) The results obtained from the experiment conducted on the velocity control system composed of the meter-out control system in the same procedure as in the above (1) are as follows: When the supply pressure is varied with the external load being kept constant, the cushion pressure was increased to 8 bar, 10 bar and 12 bar respectively, which were twice as high as the respective supply pressure and the cushion stroke time was 0.4 second identically. On the other hand, when the external load was increased with the supply pressure being kept constant, the cushion pressure was rapidly increased to 7.8 bar, 9.2 bar and 12.5 bar respectively, and the cushion stroke time was 0.4 second constantly and the total response time was longer than that of the meter-in control system.

Therefore, it has been identified that the characteristics of the cushion area are related with the external load, having no relation with the supply pressure.

(3) The results obtained by comparing the characteristics between the meter-in control system and the meter-out control system are as follows: The total cylinder respondence of the meter-in control system was about 0.6 second faster than that of the meter-out control

system and it was varied greatly depending upon the external condition, but the meter-out control system's respondence was almost constant, which was longer than the meter-in control system's respondence. But since the internal pressure, which was almost the same as the supply pressure, existed in the cylinder, its stability was superior and its cushioning capability was also better. Therefore, it has been demonstrated that it is preferable to adopt the meter-out control system when the velocity control system is applied industrially.

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