Displacement Control of Pneumatic Actuator Equipped with PLC and Proximity Sensors

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PLC와 근접센서를 이용한 공압 실린더의 변위제어

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Abstract

A pneumatic system was proposed to evaluate displacement accuracy of the pneumatic actuator without external load and to analyze capability of integration of the proposed valve system. The proposed pneumatic system consisted of a combination of pneumatic valves, two proximity sensors, and a programmable logic controller(PLC). The position controller is based on the PLC controller connected with the proximity sensors. Displacement accuracy of the pneumatic cylinder stroke was tested by varying air pressures of the supply and discharge-side and strokes of the pneumatic cylinder. The displacement accuracy of the pneumatic cylinder stroke increased as the supply and discharge side of air pressure increased at the stroke length of 133mm. Also the displacement accuracy increased as the stroke length increased with a fixed supply and discharge side of air pressure of the pneumatic cylinder as 3.5 and 4.5kg/cm^2, respectively. The most accurate displacement of the pneumatic cylinder(i.e., standard deviation of 0.01mm) was obtained at the supply and discharge side of air pressure of 4.0 and 5.0kg/cm^2, respectively, and strokes of 170 and 190 mm among arbitrarily selected supply and discharge side air pressures and strokes.

Key Words : Position Control(위치제어), Repeatability(반복성), Pneumatic Cylinder(공압 실린더), Valve System(밸브장치), Accuracy(정확도), Allowable Error(허용오차)

1. Introduction

The fluid power products are widely used in industries such as the automation assembly of products and equipments, high-tech machine tools, air crafts, trains, and etc[1]. As the industrial development progresses, its related

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fluid power products are needed to be developed and required in various industrial fields.

The development of the fluid power products is initiated by FESTO in German, SMC in Japan, and etc, and then many industries develop and supply new fluid power products. Thus, industries using fluid power products easily apply those products on automation facilities of assembling, processing and robots. In the nation, fluid power products are have been used widely as industries grow rapidly after 1970, and then domestic industries hold original technologies to manufacture about 80% of fluid power products after 1980.

Present high-tech industries require more precise fluid power products and depend on the advanced technology in many applications(2). Specially, the precise control of the pneumatic power system is yet to be developed among the fluid power technology(3). Precise control of the hydraulic cylinder is possible within ±0.01mm by using the hydraulic servo valve. However, precise and accurate control of the pneumatic cylinder is very difficult due to peculiarity of the pressurized air(4,5), and is experiencing many bottlenecks in manufacturing facilities such as the automation and production facilities. Manufacturing industries use many fluid power valves and cylinders to construct the automation facilities since these products are less expensive and easy to design, good for precision and productivity, and easy for repair and maintenance(6).

This research proposed a position control system of the pneumatic cylinder consisted of pneumatic valves, proximity sensors, and a PLC, and analyzed the repeatability and accuracy of the displacement of the pneumatic cylinder. The displacement of the cylinder stroke was controlled by balancing supply and discharge sides of air pressure of a cylinder by a combination of pneumatic valves activated by the PLC connected with the proximity sensors.

2. Materials and Methods

2.1 Position Control System of the Pneumatic Cylinder

The position control system of the pneumatic cylinder consisted of a frame, a compressor, an air filter, a regulator, a lubricator, a pressure valve, a check valve, four two-port valves, two three-port valves, two miniature valves, a pneumatic cylinder, two proximity sensors, a PLC, and a control software(Fig. 1).

The pneumatic cylinder used for this research was manufactured by ISTC Co.(Model N50-S300). The maximum pressure of the compressor(Model KC150H Kohands Co.) was 861.875kPa(125 psi).

The displacement of strokes of the pneumatic cylinder was measured by using a dial gage(Model No. 2046S Mitutoyo). The dial gage was installed at a metal block adjacent to the proximity sensors(Bottom right-hand side of Fig. 1). The proximity sensors and the dial gage designed to be slided at a sliding rod. These could be set at a desired position.

The displacement of a stroke was measured by a contact point of the dial gage. The contact point of the dial gage slided to a curved side surface of a plate attached to a spool, which was installed at the end of the cylinder rod. When the cylinder rod was stopped at a predetermined position(i.e., a location of the proximity sensors), the dial gage indicated a displacement of the stroke of the pneumatic cylinder.

Once a position of the proximity sensors was fixed, the cylinder rod should be stopped in front of the proximity sensors by activation of pneumatic valves controlled by the PLC. The PLC was initiated by signals of the proximity sensors.

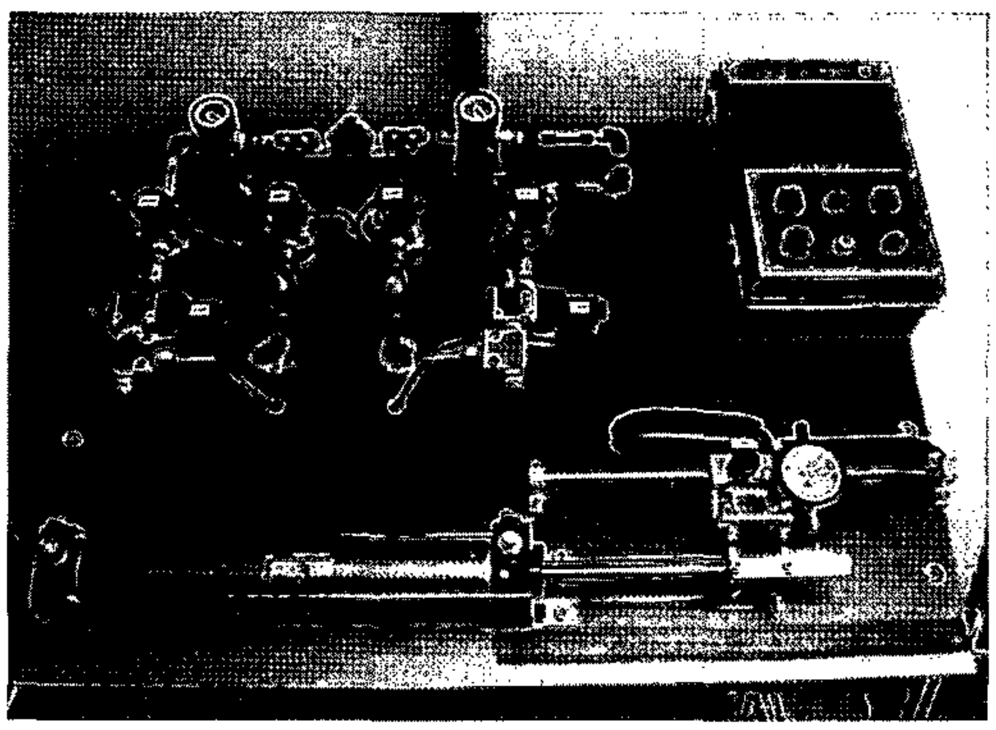

Fig. 1 Photograph of the position control system of a pneumatic cylinder

2.2 Circuit of Position Control of the Pneumatic Cylinder

A circuit of the pneumatic cylinder system was designed and manufactured as shown in Fig. 2. The circuit consisted of a compressor, an air filter, a regulator, a lubricator, four 2-port valves, a 3-port valve, two miniature-pressurize valves, two speed controllers, a pressure valve, a check valve, and a pneumatic cylinder. The valves on the left-hand side from the center in Fig. 2 controlled the forward movement of the cylinder and the valves on the right-hand side controlled the backward movement of the pneumatic cylinder associated with the PLC and signals from proximity sensors.

2.3 Electric Circuit of the Position Control System of the Pneumatic Cylinder

Fig. 3 shows an electric circuit to activate the pneumatic valves and the proximity sensors, and to operate the

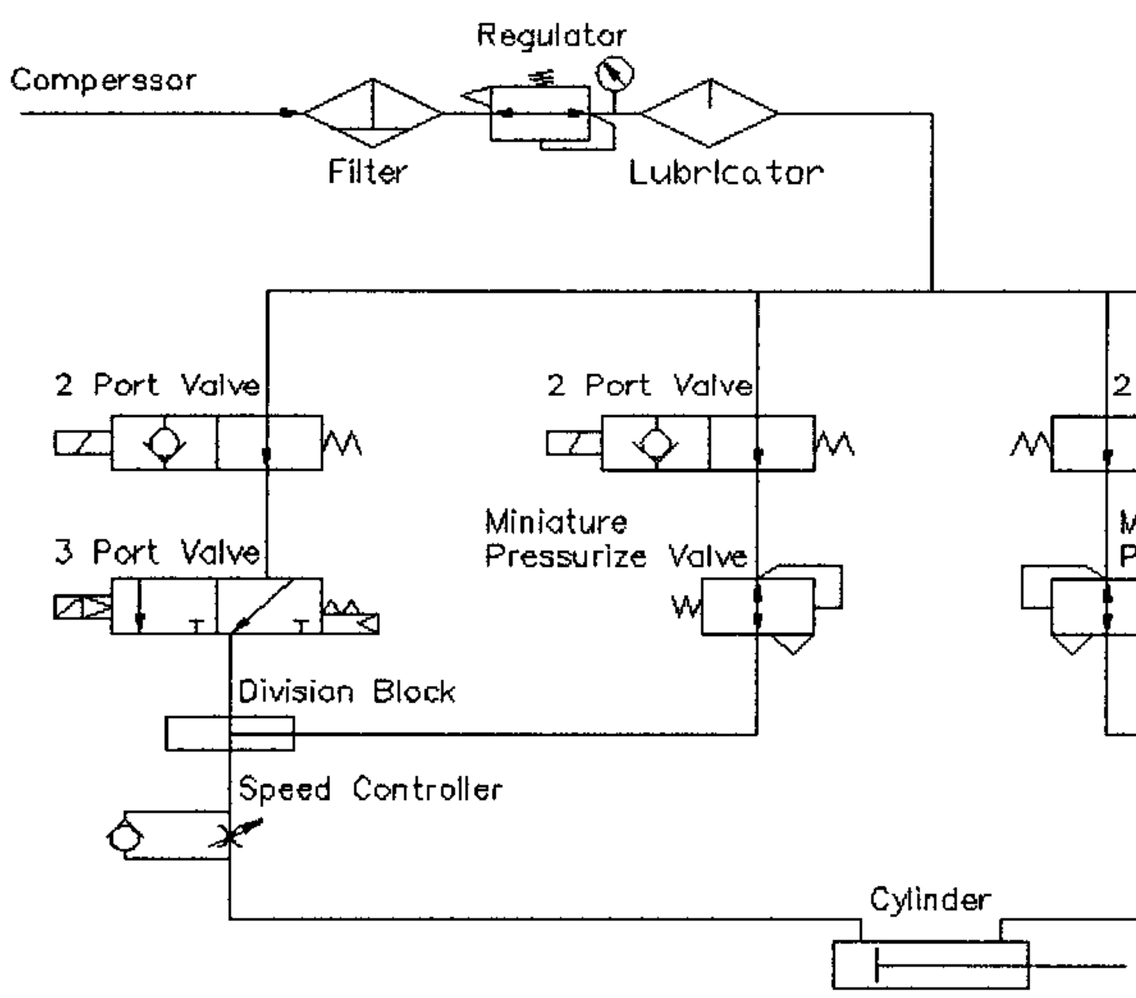

Fig. 2 Position control circuit of an experimental pneumatic system

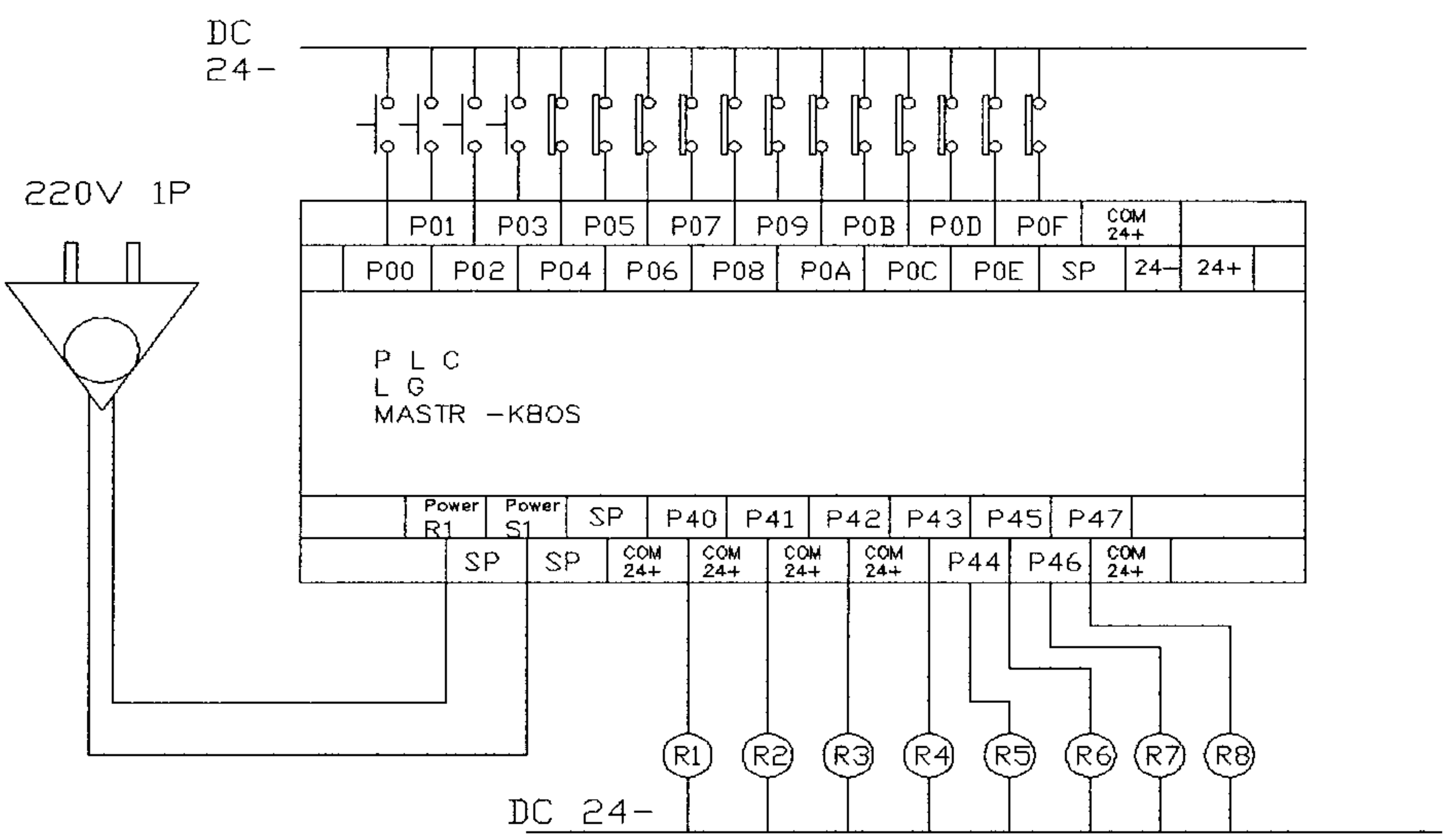

Fig. 3 Diagram of the electric circuit of the position control of the pneumatic system with the PLC

Table 1 Description of the electric circuit connection

Pin Number	Symbol	Description	Pin Number	Symbol	Description
P000	SET/SW	Manual/Auto switch	P040	RY#1	Forward solenoid valve #1
P001	PB/SW	Auto start push-button switch	P041	RY#2	SP(Surge Power)
P002	PB/SW	Manual forward push-button switch	P042	RY#3	Forward solenoid valve #2
P003	PB/SW	Manual backward push-button switch	P043	RY#4	Forward solenoid valve #3
P004	LS/SW	Proximity sensor #1	P044	RY#5	Backward solenoid valve #1
P005	LS/SW	Proximity sensor #2	P045	RY#6	SP(Surge Power)
P006	-	-	P046	RY#7	Backward solenoid valve #2
P007	-	-	P047	RY#8	Backward solenoid valve #3
P008	-	-	COM	DC 24V+COM	

pneumatic system. The system was designed to be operated by a control panel. The control panel consisted of a LED of the power source, an On/Off switch, an auto/manual switch, an automatic operation switch, a push-button switches for forward and backward movement of the pneumatic cylinder rod. Electric connections between the system and the PLC are shown in Table 1.

2.4 Operation of the Pneumatic Cylinder System

The system was designed to activate the cylinder either manually or automatically. The manual operation allowed to check malfunctioning of the pneumatic system such as out of a limit position of the cylinder stroke or to check air pressure at the supply and discharge side of the cylinder. The air pressure at the supply- and discharge-side of the cylinder should be adjusted by using the miniature pressurized valve to maintain the almost same pressure before start the experiment.

The displacement of the pneumatic cylinder stroke was controlled by activating valves which were powered by the PLC. The PLC was initiated by a signal from the proximity sensor. When the system was initiated and the right-hand side of the spool reached to the first proximity sensor(left-hand side of the proximity sensors in Fig. 1), a signal from the proximity sensor sent to the PLC. The PLC then turned on the valves at the right-hand side in Fig. 1 and pressurized the discharge-side of the cylinder until the right-hand side of the spool reached to the second proximity sensor(right-hand side one in Fig. 2). At the same time the cylinder rod stopped, and the dial gage indicated a displacement of the cylinder rod.

2.5 Test Methods

Accuracy and repeatability of the displacement of the stroke of the pneumatic cylinder was tested as follow. The air pressure at supply- and discharge-side of the pneumatic system was adjusted using the regulator(ISTC Co., Ltd) according to a length of stroke by running the system. The length of a stroke was predetermined by locating a position of the proximity sensors. The displacement of the stroke of the pneumatic cylinder was measured using the dial gage(Mitutoyo, Model No. 2046S).

The accuracy of displacements of the pneumatic cylinder stroke was tested with an arbitrary selected cylinder stroke of 133mm by varying the air pressure of the supply and discharge side of the pneumatic cylinder as 2.5/3.5, 3.0/4.0, and 3.5/4.5kg/cm^2 to analyze effect of the air pressure for the accuracy of the stroke. This test was repeated 50 times at each air pressure condition and was replicated three times.

Then, accuracy of the displacement of the pneumatic cylinder was tested by varying the cylinder stroke with the most accurate displacement condition of the air pressure of the supply and discharge side of the pneumatic cylinder.

Also, at various air pressures of the supply and discharge side of the pneumatic cylinder as 2.3/3.0, 3.5/4.5, and

4.0/5.0kg/cm^2, the accuracy of displacements of the stroke was tested by varying the length of the stroke. The length of the stroke was selected before the test at each air pressure. This test was repeated 50 times and replicated three times.

3. Results and Discussion

3.1 Accuracy of the Displacement According to Variation of the Air Pressure

Table 2 shows results of the test of the displacement accuracy of the stroke of the pneumatic cylinder system. The highest accuracy was obtained at the supply and discharge side of the air pressure as 3.5 and 4.5kg/cm^2, respectively, at the fixed cylinder stroke of 133mm. At this condition, the variation of displacement of the cylinder stroke ranged 1.07 ~ 1.11mm. The average and standard deviation of displacements of the stroke was 1.09mm and 0.01mm, respectively. Fig. 4 shows the variation of the displacement of the pneumatic actuator with various supply and discharge side air pressures as shown at Table 2.

This result was considered to be due to more relatively stable condition at high air pressure of the supply and discharge sides of the cylinder to balance out each other.

Table 2 Variation of the displacement of the fixed cylinder stroke with various supply and discharge air pressures

Supply/ discharge pressure (kg/m^2)	Stroke (mm)	Max. variation (mm)	Min. variation (mm)	Mean (mm)	STDV (mm)
2.5/3.5	133	1.23	1.09	1.12	0.03
3.0/4.0	133	1.28	1.10	1.14	0.04
3.5/4.5	133	1.11	1.07	1.09	0.01

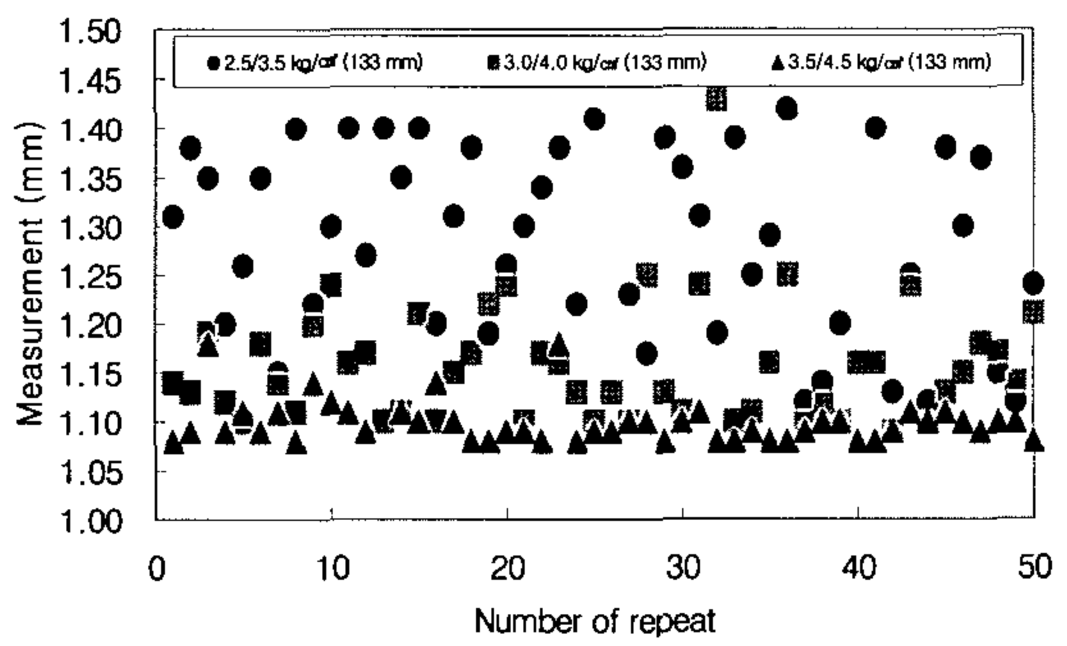

Fig. 4 Variation of displacements of the pneumatic cylinder stroke with various supply and discharge side air pressures and a fixed stroke of 133mm

3.2 Accuracy of the Displacement According to Variation of the Stroke Length

Fig. 5 shows the variation of displacements of the cylinder stroke with various cylinder strokes as 81mm, 110mm, and 140mm with the fixed air pressure of the supply and discharge side as 3.5 and 4.5kg/cm^2, respectively.

The most accurate displacement of the cylinder stroke was obtained at the longest cylinder stroke of 140mm. The max. and min. variation of the displacement of the stroke was 1.26 and 1.00mm, respectively. The average and standard deviation of the displacement was 1.14 and 0.05mm, respectively.

In Fig. 5, variation of the displacement with the stroke of 81mm was relatively wider than variation of the displacement with the stroke of 110 and 140mm.

This result was considered to be due to, under the fixed air pressure, reduced extraction speed of the cylinder rod

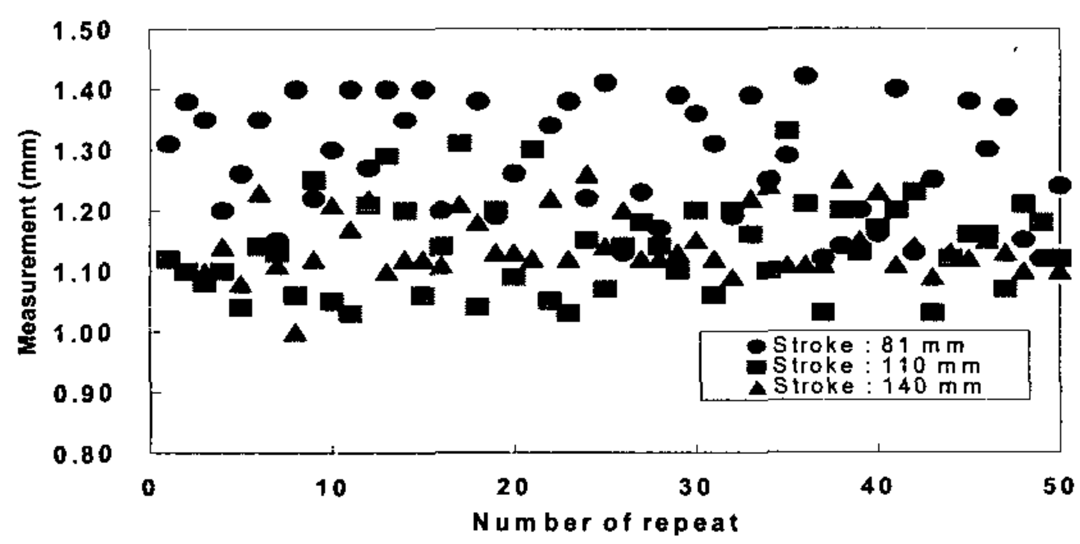

Fig. 5 Variation of displacements of the pneumatic cylinder stroke with the supply and discharge side air pressure as 3.5 and 4.5kg/cm^2, respectively

associated with instantaneous pressure drop inside the cylinder and accurate sensing reaction of the proximity sensors as the stroke length increased.

3.3 Accuracy of the Displacement of the Pneumatic Cylinder Stroke with Various Cylinder Strokes and the Air Pressures

Table 3 shows a summary of the displacement of the pneumatic cylinder stroke with various strokes and air pressures of supply and discharge side of the pneumatic cylinder. The standard deviation of the displacement of the pneumatic cylinder stroke decreased as the air pressure of supply and discharge side of the cylinder increased. Also, the standard deviation of the displacement of the pneumatic cylinder stroke decreased as the cylinder stroke increased.

From results of above three tests, the accuracy of the displacement of the stroke was largely affected by the air pressure and the stroke.

In this research a proper air pressure adjustment at the supply and discharge side of the pneumatic cylinder was necessary before the tests to balance the air pressure out on each side of the cylinder. This adjustment required tedious repeat operation for the test by checking cylinder rod movement.

The air pressure balancing at the supply and discharge side of the pneumatic cylinder for the position control of the stroke was needed to be improved for more accurate displacement.

This research found a problem like the cylinder rod passed over the proximity sensor while it extracted with short stroke of about 5cm. This was considered to be due to a high extraction speed of the cylinder rod and poor sensing capability of the proximity sensors at relatively high extraction speed of the cylinder rod. This problem would be solved for further study. Also this research would be continued with external load application to the cylinder.

Another problem found from this research was slow location of the piston rod at the desired position when the piston rod reached near to the proximity sensors. This phenomenon was due to lagged interface between the proximity sensor and the PLC due to interaction between the proximity sensors and the PLC to activate pneumatic valves to balance the supply and discharge side of the air pressure in the cylinder.

Table 3 Displacement variation of the pneumatic cylinder stroke with various air pressures and strokes

Air pressure Supply/discharge (kg/cm^2)	Stroke (mm)	Displacement (mm)		Mean (mm)	STDV (mm)
		Max. (mm)	Min. (mm)		
2.3/3.0	70	1.58	1.00	1.34	0.14
2.3/3.0	100	1.32	0.33	1.14	0.16
2.3/3.0	130	1.41	1.05	1.18	0.10
3.5/4.5	80	1.42	1.12	1.28	0.10
3.5/4.5	110	1.33	1.03	1.14	0.08
3.5/4.5	130	1.26	1.00	1.14	0.05
3.5/4.5	160	1.18	1.11	1.14	0.02
4.0/5.0	140	1.19	1.08	1.11	0.02
4.0/5.0	170	1.21	1.18	1.20	0.01
4.0/5.0	190	1.27	1.23	1.25	0.01

4. Conclusion

This research analyzed the possibility of the position control of the pneumatic cylinder using the pneumatic valves, proximity sensors and PLC. The proposed pneumatic system was capable of controlling the position of the actuator within 0.1mm, and the repeatability of the stroke was very reliable.

Based on results from this research, a small and simple valve system could be developed for the position control of the pneumatic actuator for further research. Following is summary of results obtained from this research.

(1) The position control of the pneumatic actuator(air pressure of less than $5kg/cm^2$) was possible using a feedback control system.

(2) The position control system developed from this research was capable of controlling the pneumatic

cylinder stroke within the standard deviation of 0.01mm.

(3) The technology of the position control of the pneumatic actuator proposed from this research was capable of controlling the position in automation facility.

(4) The technology of the position control of the pneumatic cylinder stroke proposed from this research showed a possibility for miniaturization and integration of a valve system necessary in the position control of the pneumatic actuator.

References

(1) Choi, G. S., Lee, H. K., and Choi, G. H., 1998, "A Study on Tracking Position Control of Pneumatic Actuators Using Neural Network," *IEEE Trans Robotics and Automation*, pp. 1749~1753.

(2) Inohana, K., Fujiwara, A., and Ishida, Y., 1996, "Hybrid I-PD Control for Pneumatic Cylinders with Fuzzy Theory," *Proceedings of the 11th KACC*, pp. 193~196.

(3) Minamiyama, Y., Kiyota, T., Sasaki, T., and Sugimoto, N., 2007, "Application of Passive Dynamic Control to Pneumatic Cylinders," *IEEE International Conference on Robotics and Automation*, pp. 4497~4502.

(4) Kim, I. S., Kim, K. W., Jeong, Y. J., Son, J. S., Song, C. J., and Park, J. S., 1999, "A study on the Selection of Controller for Position of a Pneumatic Cylinder," *Journal of the Korean Society of Machine Tool Engineers*, Vol. 8, No. 6, pp. 35~42.

(5) Jang, J. S., 2002, "Position Control of a Pneumatic Cylinder with a Nonlinear Compensator and a Disturbance Observer," *Transactions of the KSME. A*, Vol. 26, No. 9, pp. 1795~1805.

(6) Newsletter of the KASAS, 1999, "Position Control System Using Pneumatic Pressure," <http://www.kasas.or.kr/meau01/content/kasas22-1.htm>.