한국기계가공학회지, 제10권, 제6호, pp. 50-55 (2011. 12)
Journal of the Korean Society of Manufacturing Process Engineers, Vol. 10, No. 6, pp. 50-55 (2011. 12)

공압 실린더 액츄에이터 위치제어

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Position Control of a Pneumatic Cylinder Actuator using PLC and Proximity Sensors

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(Received 29 April 2011; received in revised form 28 November 2011; accepted 6 December 2011)

ABSTRACT

The fluid power products are widely used in current industrial area such as automation of products and equipment assembly, high-tech machine tool, aircraft, train, and etc. As the development of industry is in progress, the development of the fluid power products is demanding and it is required in every industrial area. This research proposed a pneumatic system to evaluate displacement accuracy of the pneumatic actuator without external load and to analyze capability of integration of the valve system. The pneumatic system consisted of a combination of pneumatic actuator, four two-port valves, two three-port valves, two pressure valve, a check valve, two proximity sensors, and a program logic controller (PLC). The position controller is based on the PLC connected with the proximity sensors. The maximum air pressure applied for tests was 49.05N/㎠ and the displacement accuracy of a stroke was measured using a dial gauge. The supply- and discharge-side of air pressure and the length of the stroke of the pneumatic cylinder were varied The test of the position control of the pneumatic cylinder was carried out 50 times at each supply- and discharge-side air pressure of 24.53/34.34, 29.43/39.24, 34.34/44.15, and 39.24/49.05N/㎠ and replicated three times. The accuracy of the displacement of the pneumatic cylinder stroke increased as the supply- and discharge-side of air pressure increased with the stroke length of 133mm. Also the displacement accuracy increased as the stroke length increased with the fixed supply- and discharge-side of air pressure of the pneumatic cylinder as 34.34 and 44.15N/㎠, respectively. The most accurate displacement of the pneumatic cylinder was obtained at the supply- and discharge-side of air pressure of 39.24 and 49.05N/㎠, respectively, and strokes of 170 and 190mm.

Key Words : Position Control, Repeatability, Pneumatic Cylinder, Valve System, Accuracy, Allowable Error

1. Introduction

The fluid power products are widely used industrial fields such as in automation of the products and equipments assembly, high-tech machine tools, aircrafts, trains, and etc. As the industrial development in progress,

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its related fluid power products need to be developed and required in various industrial fields.

Development of the fluid power products are initiated by FESTO in German, SMC in Japan, and etc, and then many industries develop and supply new fluid power products in present. 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. Specially, the precise control of the pneumatic power system is yet to be developed among the fluid power technology. 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, and is experiencing many bottlenecks in manufacturing facilities such as the automation and production facilities. Manufacturing companies 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.

The position control method by the structures and equipments is being widely used for fluid power cylinders. This method compulsory stops and controls a position of the cylinder stroke at the end of the cylinder stroke or stops the cylinder stroke in a middle of stroke by installing a stopper. This method is widely used since it has a good stopping accuracy and its cost is low. But, this method generates noise, vibration, wear and tear by the contact of impulse between a actuator and a stopper in high speed position control according to the impulse, which is proportional to the square of speed.

This research proposed a position control system of the pneumatic cylinder consisted of pneumatic valves, proximity sensors, and a program logic controller (PLC), and analyzed the repeatability and accuracy of the displacement of the pneumatic cylinder. The displacement of the pneumatic cylinder stroke was controlled by balancing supply and discharge sides of air pressure of the cylinder by combinations 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 small valves, a pneumatic cylinder, two proximity sensors, a PLC, and a control software(Fig. 1).

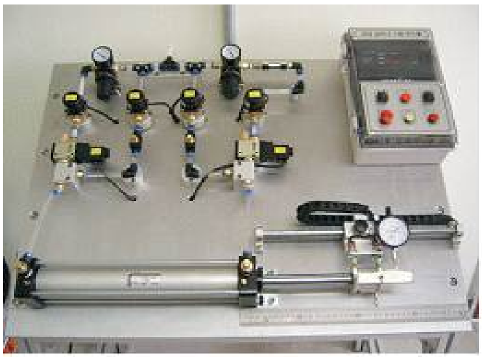

Fig. 1 Photograph of the position control system of a pneumatic cylinder

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

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

The displacement of strokes of the pneumatic cylinder was measured a 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. Thus, once the cylinder rod was stopped at a predetermined position (i.e., a location of the proximity sensors), the dial gage indicated a displacement of a stroke of the pneumatic cylinder.

The proximity sensors were installed at a metal block and the metal block moved along a sliding rod such that the position of the proximity sensors was adjustable along the sliding rod. Once a position of the proximity sensors was fixed, the stroke of the cylinder should be stopped at a predetermined position by control of the PLC and pneumatic valves which were initiated by the signal of the proximity sensors.

2.2 Circuit of Position Control of the Pneumatic Cylinder

A circuit of the pneumatic cylinder system was designed and manufactured as shown 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 with the PLC and signals from proximity sensors.

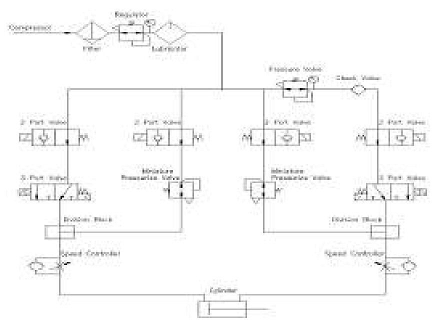

Fig. 2 Position control circuit of an experimental pneumatic system

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

Fig. 3 shows the electric circuit to power the pneumatic system, to activate the pneumatic valves and the proximity sensors, and to operate the 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 swift switch, an automatic operation switch, a push-button switch of forward movement, and a push button switch of backward movement of the pneumatic cylinder. Table 1 explains the descriptions of the electric connection between the system and the PLC.

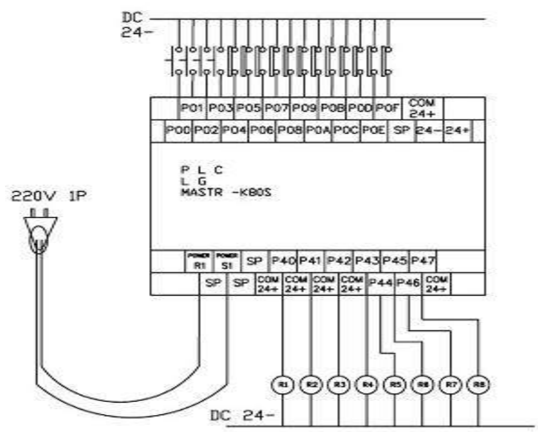

Fig. 3 Diagram of the electric circuit of the position control of the pneumatic system with the PLC

2.4 Operation of the Pneumatic Cylinder System

The pneumatic cylinder system was designed to activate the cylinder either manually or automatically such that it allowed to check the operation of the pneumatic system or to check the position control of the system after adjusted a displacement position of the cylinder by setting a location of the proximity sensors as desired.

The position of the pneumatic cylinder was controlled by activating the valves which was powered by the PLC. The PLC was initiated by a signal from the proximity sensor. When the system initiated and the right-hand side

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

of the spool reached to the first proximity sensor (left-hand side one in Fig. 1), a signal from the proximity sensor sent to the PLC. The PLC then turned on the valves on 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 and set before experiment using the regulator (ISTC Co., Ltd) according to a length of stroke by running the system.

The accuracy of the displacement 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 24.53/34.34, 29.43/39.24, and 34.34/44.15N/㎠ to analyze effect of the air pressure for the accuracy of the stroke. The test was repeated 50 times at each air pressure condition and was replicated three times.

Then, accuracy of the displacement of the pneumatic cylinder stroke 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 each air pressure of the supply- and discharge-side of the pneumatic cylinder of 22.56/29.43, 34.34/44.15, 39.24/49.05N/㎠, the accuracy of the displacement of the pneumatic cylinder was test by varying the length of the cylinder stroke. This test also repeated 50 times and was replicated three times. The length of the cylinder stroke at each air pressure was selected before the test.

3. Results and discussion

3.1 Accuracy of the Displacement According to Variation of the Supply- and Discharge-side of Air Pressure

Results of the test of the displacement accuracy of the stroke of the pneumatic cylinder system was shown in Table 2. The highest accuracy was obtained at the supply- and discharge-side of the air pressure as 34.34 and 44.15N/㎠, respectively, with the fixed cylinder stroke of 133mm. The variation of displacement of the cylinder stroke ranged 1.07-1.11mm. The average and standard deviation was 1.09mm and 0.01mm, respectively.

Table 2 Displacement of the cylinder stroke with various supply and discharge air pressure

Supply/discharge air pressure (N/㎠)	Stroke (mm)	Max. variation (mm)	Min. variation (mm)	Mean (mm)	STDV
24.53/34.34	133	1.23	1.09	1.12	0.03
29.43/39.24	133	1.28	1.10	1.14	0.04
34.34/44.15	133	1.11	1.07	1.09	0.01

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.

3.2 Accuracy of the Displacement According to Variation of the Stroke

Fig. 4 shows the variation of displacements of the cylinder stroke with various cylinder strokes as 81mm, 110mm, and 140mm with fixed air pressure of the supply- and discharge-side as 34.34 and 44.15N/㎠, respectively.

The result shows that the most accurate displacement of the cylinder stroke was with 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. 4, 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, under the fixed air pressure, reduced extraction speed of the cylinder rod associated with instantaneous pressure drop inside of the cylinder and accurate sensing reaction of the proximity sensors as the stroke length increased.

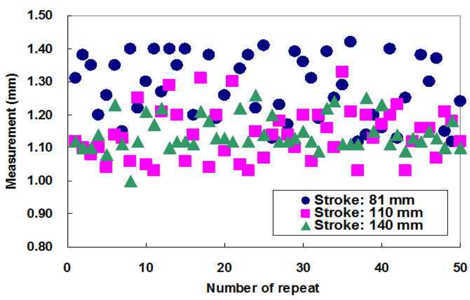

Fig. 4 Displacement variation of the pneumatic cylinder stroke with the air pressure of supply- and discharge-side of 34.34 and 44.15N/㎠, respectively

3.3 Accuracy of the Displacement of the Pneumatic Cylinder Stroke According to Variation of the Cylinder Stroke and the Air Pressure

Table 3 shows a summary of the displacement of the pneumatic cylinder stroke with various lengths of stroke 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 increased. Also, as the cylinder stroke increased the standard deviation of the displacement of the pneumatic cylinder stroke decreased.

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

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.

This research found a problem like the cylinder rod passing over the proximity sensor while it extracted with a 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. This problem needed to be solved for further study.

Another problem found was slow location of the cylinder rod at the desired position when the cylinder rod reached near to the proximity sensors. This phenomenon was due to lagged interface between the proximity sensor and the PLC caused by 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 pneumatic cylinder.

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

Air pressure Supply/discharge (N/㎠)	Stroke (mm)	Displacement(mm)		Mean (mm)	STDV
		Max.	Min.		
22.56/29.43	70	1.58	1.00	1.34	0.14
22.56/29.43	100	1.32	0.33	1.14	0.16
22.56/29.43	130	1.41	1.05	1.18	0.10
34.34/44.15	80	1.42	1.12	1.28	0.10
34.34/44.15	110	1.33	1.03	1.14	0.08
34.34/44.15	130	1.26	1.00	1.14	0.05
34.34/44.15	160	1.18	1.11	1.14	0.02
39.24/49.05	140	1.19	1.08	1.11	0.02
39.24/49.05	170	1.21	1.18	1.20	0.01
39.24/49.05	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 pneumatic valves, proximity sensors, and PLC. The proposed pneumatic system was capable of controlling the position of actuator within 0.1mm and the repeatability of the stroke was very reliable.

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

The position control of the pneumatic system (air pressure of less than 49.05N/㎠) was possible using a feedback control system.

The position control system proposed from this research was capable of controlling the pneumatic cylinder stroke with the standard deviation of 0.01mm.

The technology of the position control of the pneumatic cylinder stroke proposed from this research was capable of control the position control in automation facility.

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

Acknowledgment

This work was supported by a 2-Year Research Grant of Pusan National University.

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