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Dynamic Measurement of Extra Long Stroke Cylinder in the Pneumatic System

Ho Chang¹, Chou-wei Lan¹ and Liang-Chia Chen²

¹ Department of Mechanical Engineering, National Taipei University of Technology, Taiwan, China
² Graduate Institute of Automation Technology, National Taipei University of Technology, Taiwan, China

E-mail: f10381@ntut.edu.tw

Abstract. This paper sets up the measure and control system of the dynamic characteristics of the extra long stroke cylinder. In the different types of the control conditions (e.g. different control law, operating pressure and direct control valves), using the measure and control system to measure the relation between the pressure and the velocity of the motion of the long stroke cylinder and to observe the stick slip phenomenon of the motion of the long stroke cylinder. In the innovate measurement system, two pressure sensors are set on the long stroke cylinder to measure the difference of the pressure between the inlet and the exhaust of the long stroke cylinder. In additions, a draw line encoder is set on the system to measure the position and the velocity of the motion of the long stroke cylinder. The measuring data of the measure system is transferred to the computer via A/D interface card and counter card, and Home-made program of Haptic Interface Device is used to control the system, saving the data of the motion of the long stroke cylinder. The system uses different types of direction control valve to control the motion of the long stroke cylinder and compares the different of the motion of the long stroke cylinder. The results show that the motion of the cylinder that pauses in the middle of the cylinder stroke and causes the stick slip phenomenon is more violent than the stick slip phenomenon in other position. When the length of the pause time reaches the some range, the acceleration of the motion of the cylinder will be rised substantially. This paper not only focuses on the testing method of the dynamic characteristics of the motion of the long stroke cylinder, but also includes the analysis of the dynamic characteristics of the motion of the long stroke cylinder. It provides the data of the dynamic characteristics of the motion of the long stroke cylinder to improve and design the pneumatic system of the long stroke cylinder.

1. Introduction

1.1. Pneumatic System

Pneumatic system is a time varying system. The system parameters of Pneumatic system would be influenced by the different environmental parameters (temperature, operation time, load, etc.). Because of the compressibility, low viscosity and friction of air, the nonlinear phenomena of the valve, Hysteresis phenomenon of the coil and baseline wander of the spool motion the control of pneumatic system is difficult. [1,2] The stick slip phenomenon is a interesting program of the pneumatic position control system. Because the stick slip phenomenon would be influence the motion of the pneumatic actuator, so this paper will be research and discuss the effect of the stick slip phenomenon. Recently the servo control system is replacing the precision mechanical system gradually. Even the same
pneumatic cylinder receives the same signal in the same environment, the leakage rates and friction of the pneumatic cylinder would be make the pneumatic cylinder output the different Output Response and cause the control of the pneumatic cylinder can’t achieve the ideal synchronous control [3].

1.2. The measure and control system of the extra long stroke cylinder
This paper design and set up a dynamic simulation and measuring system of the extra long stroke cylinder, shown in Figure 1. The simulation and measuring system can measure the dynamic data of the motion of pneumatic cylinder and observe the stick slip phenomena of the pneumatic cylinder.

Because the air volume of the extra long stroke pneumatic cylinder is larger than the common pneumatic cylinder, so the compressibility of air makes the position and velocity control of the pneumatic cylinder motion is difficult. If want to precise control the position and velocity of the extra long stroke cylinder, research the dynamic characteristic of the cylinder motion in different operation law is necessary. The simulation experiment is using different control parameter. In the dynamic simulation and measuring system of the extra long stroke cylinder, use two piezo-resistive pressure sensors to measure the pressures of the inlet and the exhaust of the long stroke cylinder, and use a draw line encoder to measure the position and velocity of the pneumatic cylinder motion. The measuring data of the measure system is transferred to the computer via A/D interface card and counter card. When the moment of the pneumatic cylinder motion, the friction of the cylinder is getting decrease and the stick slip phenomenon would be occur. The stick slip phenomenon makes the system instability and cause the position control is not precise. [4] According to the data of the pneumatic cylinder simulation experiment, the dynamic characteristic of the extra long stroke cylinder can be obtained and provide the control parameter of the pneumatic system for designer.

2. Experimental system
The purpose of the simulation and measuring system is research the stick slip phenomenon in the different pause position of the pneumatic cylinder motion and analyze the relation between the pressure variation and the stick slip phenomenon. When the cylinder pauses in the same position, the experiment sets the different length of the pause times and analyzes the relation between the length of the pause times and the velocity variation.

The equipments of the simulation and measuring system of the extra long stroke cylinder have shown in figure 2. The stroke of the cylinder is 2100mm. The pneumatic system uses a 5/3 direction control valve and two 2/2 switch valves to control the pneumatic cylinder motion. The load of the pneumatic cylinder is 50 kg.

![Figure 1. The simulation and measuring system of the pneumatic cylinder.](image)
This paper designs two experiments, the experiment (1) is focus on the relation between the pressure variation and the stick slip phenomenon and the experiment (2) is focus on the relation between the length of the pause times and the velocity variation. The experiment (1) sets the operation pressure of the pneumatic on 3 kgf/cm², 4 kgf/cm² and 5 kgf/cm², and the pause position on 700 mm, 1050 mm and 1400 mm of the cylinder stroke. The experiment (2) sets the operation pressure of the pneumatic on 3 kgf/cm², 4 kgf/cm² and 5 kgf/cm², the pause position on 700 mm, 1050 mm and 1400 mm of the cylinder stroke, and the pause time on 1 sec, 2 sec, 3 sec, 4 sec and 5 sec. The experiment (1), the pneumatic cylinder starts on the initial position and pauses on the position 700 mm, 1050 mm and 1400 mm of the cylinder stroke. When the cylinder reaches the pause position, the proximity-switch would be closed the 5/3 direction control valve and stop the motion of the cylinder. The experiment (2), the pneumatic cylinder starts on the initial position and pauses on the position 700 mm, 1050 mm and 1400 mm of the cylinder stroke. Then after the pause time, the pneumatic cylinder has been driven again. Until the cylinder reaches the terminal position of the cylinder stroke, the cylinder has been stopped.

3. Results and discussion

3.1. The experiment (1)
The experiment (1) saves the data of the pressure, displacement and velocity of the motion of the pneumatic cylinder. When the pneumatic cylinder reaches the pause position, the controller would be closed the 5/3 direction control valve. Because the load of the cylinder still has kinetic energy, so the cylinder would be moved. But the air between the inlet and the exhaust of the long stroke cylinder would be stopped the motion of the cylinder. While the cylinder is getting into motionless, the stick slip phenomenon would be happened. As the pause position is in the middle of the cylinder stroke and the operation pressure is 3 kgf/cm², the error of the position is the largest of the results of the experiment (1). The results of the experiment (1) are shown in Table 1. The variations of the pressure and velocity are shown in Figure 3 and Figure 4. The variation of the pressure and velocity in the figure 4 is more stable than the variation of the pressure and velocity in the figure 3. The variation between the pressure a and pressure b in Figure 3 is violent and unbalance and according to the results of the table 1, the position control of the pneumatic cylinder in the low pressure is more difficult than the position control of the pneumatic cylinder in the high pressure and the stick slip phenomenon is apparent in the low operation pressure.

3.2. The experiment (2)
The purpose of the experiment (2) is observe the variation of the velocity between before the pause and after the pause in the different pause positions. The results of the experiment (2) are shown in
Table 2. The variations of the pressure and velocity are shown in Figure 5 and Figure 6. The variation of the velocity in the figure 6 is larger than the variation of the velocity in the figure 5 and according to the results of the experiment (2), the variation of the velocity is large in the middle of the cylinder stroke. In the low operation pressure (3 kgf/cm$^2$), as the pause time is getting to longer, the variation of the velocity is getting larger. But in the high operation pressure (5 kgf/cm$^2$), the effect of the length of the pause time to the variation of the velocity is not apparent.

Table 1. The results of the experiment (1).

| Pause position | Operation pressure | The cylinder pause position | The error of the position | The max displacement | The max velocity |
|----------------|--------------------|----------------------------|--------------------------|---------------------|-----------------|
| 700 mm         | 3 kgf/cm$^2$       | 788 mm                     | 88 mm                    | 800 mm              | 281 mm/s        |
| 700 mm         | 4 kgf/cm$^2$       | 785 mm                     | 85 mm                    | 874 mm              | 324 mm/s        |
| 700 mm         | 5 kgf/cm$^2$       | 698 mm                     | -2 mm                    | 812 mm              | 339 mm/s        |
| 1050 mm        | 3 kgf/cm$^2$       | 1157 mm                    | 107 mm                   | 1221 mm             | 344 mm/s        |
| 1050 mm        | 4 kgf/cm$^2$       | 1134 mm                    | 84 mm                    | 1221 mm             | 358 mm/s        |
| 1050 mm        | 5 kgf/cm$^2$       | 1073 mm                    | 23 mm                    | 1197 mm             | 367 mm/s        |
| 1400 mm        | 3 kgf/cm$^2$       | 1457 mm                    | 57 mm                    | 1581 mm             | 408 mm/s        |
| 1400 mm        | 4 kgf/cm$^2$       | 1457 mm                    | 57 mm                    | 1575 mm             | 418 mm/s        |
| 1400 mm        | 5 kgf/cm$^2$       | 1454 mm                    | 54 mm                    | 1475 mm             | 421 mm/s        |

Figure 3. The variation of the pressure and velocity of the experiment (1) (3 kgf/cm$^2$, 1050mm).

Figure 4. The variation of the pressure and velocity of the experiment (1) (5 kgf/cm$^2$, 1050mm).

Figure 5. The variation of the pressure and velocity of the experiment (2). (The operation pressure is 3 kgf/cm$^2$, the pause position is 1050mm, the pause time is 1 sec.)
Table 2. The results of the experiment (2).

| The operation pressure | The pause position | The max velocity before the pause | The max velocity after the pause | The pause time |
|------------------------|-------------------|----------------------------------|----------------------------------|---------------|
| 3 kgf/cm²              | 700 mm            | 300 mm/s                         | 512 mm/s                         | 1.00 sec      |
| 3 kgf/cm²              | 1050 mm           | 333 mm/s                         | 565 mm/s                         | 1.00 sec      |
| 3 kgf/cm²              | 1400 mm           | 389 mm/s                         | 543 mm/s                         | 1.00 sec      |
| 3 kgf/cm²              | 1050 mm           | 343 mm/s                         | 571 mm/s                         | 2.00 sec      |
| 3 kgf/cm²              | 1400 mm           | 382 mm/s                         | 553 mm/s                         | 2.00 sec      |
| 3 kgf/cm²              | 700 mm            | 297 mm/s                         | 509 mm/s                         | 3.00 sec      |
| 3 kgf/cm²              | 1050 mm           | 338 mm/s                         | 580 mm/s                         | 3.00 sec      |
| 3 kgf/cm²              | 1400 mm           | 385 mm/s                         | 558 mm/s                         | 3.00 sec      |
| 3 kgf/cm²              | 700 mm            | 294 mm/s                         | 527 mm/s                         | 6.00 sec      |
| 3 kgf/cm²              | 1050 mm           | 332 mm/s                         | 580 mm/s                         | 4.00 sec      |
| 3 kgf/cm²              | 1400 mm           | 386 mm/s                         | 567 mm/s                         | 4.00 sec      |
| 3 kgf/cm²              | 700 mm            | 307 mm/s                         | 539 mm/s                         | 5.00 sec      |
| 3 kgf/cm²              | 1050 mm           | 337 mm/s                         | 588 mm/s                         | 5.00 sec      |
| 3 kgf/cm²              | 1400 mm           | 383 mm/s                         | 556 mm/s                         | 5.00 sec      |

| The operation pressure | The pause position | The max velocity before the pause | The max velocity after the pause | The pause time |
|------------------------|-------------------|----------------------------------|----------------------------------|---------------|
| 5 kgf/cm²              | 700 mm            | 328 mm/s                         | 455 mm/s                         | 1.00 sec      |
| 5 kgf/cm²              | 1050 mm           | 380 mm/s                         | 661 mm/s                         | 1.00 sec      |
| 5 kgf/cm²              | 1400 mm           | 427 mm/s                         | 586 mm/s                         | 1.00 sec      |
| 5 kgf/cm²              | 700 mm            | 335 mm/s                         | 567 mm/s                         | 2.00 sec      |
| 5 kgf/cm²              | 1050 mm           | 378 mm/s                         | 689 mm/s                         | 2.00 sec      |
| 5 kgf/cm²              | 1400 mm           | 422 mm/s                         | 669 mm/s                         | 2.00 sec      |
| 5 kgf/cm²              | 700 mm            | 343 mm/s                         | 578 mm/s                         | 3.00 sec      |
| 5 kgf/cm²              | 1050 mm           | 376 mm/s                         | 677 mm/s                         | 3.00 sec      |
| 5 kgf/cm²              | 1400 mm           | 423 mm/s                         | 681 mm/s                         | 3.00 sec      |
| 5 kgf/cm²              | 700 mm            | 321 mm/s                         | 582 mm/s                         | 4.00 sec      |
| 5 kgf/cm²              | 1050 mm           | 374 mm/s                         | 669 mm/s                         | 4.00 sec      |
| 5 kgf/cm²              | 1400 mm           | 414 mm/s                         | 665 mm/s                         | 4.00 sec      |
| 5 kgf/cm²              | 700 mm            | 323 mm/s                         | 581 mm/s                         | 5.00 sec      |
| 5 kgf/cm²              | 1050 mm           | 357 mm/s                         | 688 mm/s                         | 5.00 sec      |
| 5 kgf/cm²              | 1400 mm           | 416 mm/s                         | 668 mm/s                         | 5.00 sec      |

Figure 6. The variation of the pressure and velocity of the experiment (2).
(The operation pressure is 3 kgf/cm², the pause position is 1050mm, the pause time is 5 sec )
4. Conclusion
This paper designs a dynamic simulation and measure system of the extra long stroke cylinder and obtains the following results.

- The position control of the pneumatic cylinder in the low pressure is more difficult than the position control of the pneumatic cylinder in the high pressure.
- The stick slip phenomenon is apparent in the low operation pressure.
- The variation of the velocity is large in the middle of the cylinder stroke.
- In the low operation pressure (3 kgf/cm²), as the pause time is getting to longer, the variation of the velocity is getting larger. But in the high operation pressure (5 kgf/cm²), the effect of the length of the pause time to the variation of the velocity is not apparent.

Using the dynamic simulation and measure system can obtain the dynamic characteristics of the pneumatic cylinder to improve the design of the pneumatic system. The system parameter of the experiment can provide the reference resources for the designer of the pneumatic element.

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