Proc. of the 9th Intl. Conf. of Asian Society for Precision Engg. and Nanotechnology (ASPEN 2022)
15–18 November 2022, Singapore. Edited by Nai Mui Ling Sharon and A. Senthil Kumar
doi://10.3850/978-981-18-6021-8_OR-02-0286

Multi-axis synchronous control of pneumatic cylinder for reliability tester

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KEYWORDS: Reliability tester, Pneumatic system control, Synchronized control, Proportional flow control

As most of the failures of machines or structures are called fatigue failures, reliability evaluation is one of the most important factors in design. Fatigue tester is a device that performs dynamic and static tests for material evaluation and product reliability evaluation. Most fatigue testers produce uniaxial weight due to mechanical limitations. Therefore, the test was conducted by applying three axes to each uniaxial load test. However, the actual load occurs simultaneously in the three-axis direction rather than the combination of individual load in the one-axis direction. In order to test real load, 3-axis simultaneous load test can make more realistic load. Multi-axis synchronous control is required to establish a load environment that occurs in multiple axes for a product. In addition, synchronous control allows multiple products to be tested at the same time to improve test efficiency. In this study, a controller for multi-axis synchronous control was developed. Due to the characteristics of the pneumatic system, there is a problem that the accuracy is very poor even if the control commands are synchronized. To solve this problem, the developed synchronous control algorithm compensates the phase of each axis by feedback-controlling the phase difference of each axis in real time. For displacement and load control based on feedback/feedforward, the synchronous control algorithm was applied. A user-based interface was created that allows the user to select and apply synchronous control to axes 2 to 4. The performance of the developed synchronous control algorithm was verified by conducting an experiment to control the position and load of each axis.

1. Introduction

Ensuring product stability is one of the most important considerations in design. Moving machines and products subjected to repeated loads lose material strength over time, and fatigue failure occurs. Fatigue failure occurs suddenly at a certain moment, often resulting in a serious accident. In order to prevent fatigue fractures, fatigue tests are used to prevent fractures before they occur, and to predict the service life and replacement timing of parts. A fatigue tester is a device that applies a periodic load to materials to measure their fatigue strength, and is used to evaluate the physical properties of materials and the reliability of products[1]. Most fatigue tester are performed by applying a load in one direction due to the mechanical limitations of the equipment. Fatigue tests are usually carried out on one axis and then on another axis, but it consumes a lot of time and there are many problems in reproducing the loads that actually act on multiple axes. Simultaneous multi axis load testing allows more realistic loads to be generated[2]. Multi-axis synchronous control can generate loads that act as actual multiple axes, shortening the test time. Hydraulic cylinders are commonly used in fatigue testing machines, which are capable of precise displacement control and can apply high load. However, hydraulic cylinders are expensive to introduce and maintain, and have the disadvantage of occupying a large amount of installation space[3]. Also, hydraulic oil used in cylinders increases greenhouse gas emissions and causes environmental pollution. Hydraulic oil contamination progresses rapidly due to the inflow of impurities during repeated tests, and 140 liters of hydraulic oil is used per year based on the usage capacity of 10tons. Therefore, various studies are being conducted to solve this problem by replacing hydraulic cylinders with other types of actuators such as synchronous motors and pneumatic cylinders[4]. Synchronous motors can control the rotation angle and speed with high precision and can convert this to linear motion using screws and nuts. However, when steaming screw leads for high frequency transfer, high torque must be generated for load application, which requires a large amount of electrical energy and reduces the energy rate[5]. Pneumatic cylinders are cheaper to install than hydraulic cylinders and have advantages in terms of space utilization[6]. However, the force that can be generated is lower than that of a hydraulic cylinder, and the compressibility of air makes it difficult to control force and speed at high speed and with high accuracy[7]. Therefore, despite the many advantages of pneumatic cylinders, they have not been applied to fatigue testing machines.

In this study, we developed a controller for multi-axis synchronous control. Due to the characteristics of the pneumatic system, there is a problem that even if the control commands are synchronized, the accuracy is greatly reduced. The synchronous control algorithm developed to solve this problem feedback-controls the phase difference of each axis in real time to compensate the phase of each axis. Based on the developed control algorithm, a controller for a multi-axis pneumatic fatigue tester was manufactured, a multi-axis pneumatic fatigue tester test bed was constructed, and the controller was applied to verify its performance.

2. Control algorithm

2.1 Control algorithm

Fig. 1 shows a commonly used synchronous control algorithm, the master-slave algorithm and Cross coupled control algorithm. The master-slave algorithm is a method in which slave cylinders are controlled according to a master command. It has the advantage of being relatively easy to control, since only commands are shared and each cylinder is controlled independently. However, if a problem such as a disturbance occurs in only one cylinder, the other cylinder is not affected, and the synchronization error increases. The cross coupled control algorithm is a control method that calculates and feeds back the synchronization error between cylinders in real time. It has the advantage of less synchronization error compared to the master-slave algorithm. However, there is a disadvantage that all the cylinders are affected by the disturbance generated in one cylinder and the following error greatly increases. As a result of testing each algorithm, it was confirmed that CCC is dominant in the low frequency region below 5Hz, and Master-salve is dominant in the high frequency region above 5Hz. fatigue tests are mostly performed in an environment of 5hz or higher, so the master-slave algorithm is applied.

2.2 Phase feedback control algorithm

Due to the compressibility of air, even if the master cylinder and slave cylinder receive the same command, the position and load of each cylinder are different. The Phase feedback control algorithm was developed and applied to solve the problem. Fig. 2 is the phase feedback control algorithm. Generate the same command as master-slave, use LVDT or load cell to find the phase of the maximum point of cycle, and delay the phase of slave by the phase difference between master and slave.

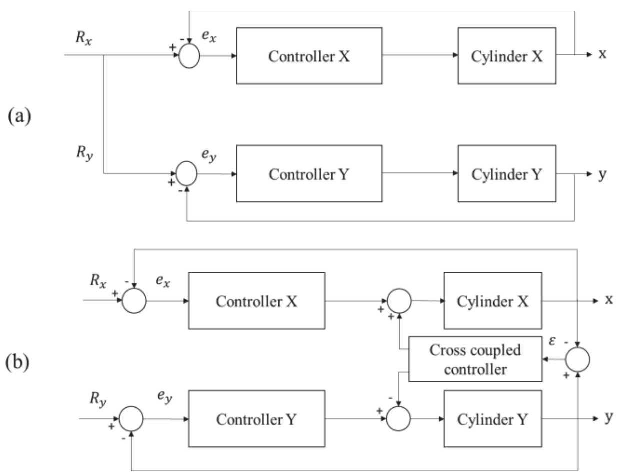

Fig. 1 Synchronous algorithm (a) Master-slave algorithm, (b) Cross coupled control algorithm,

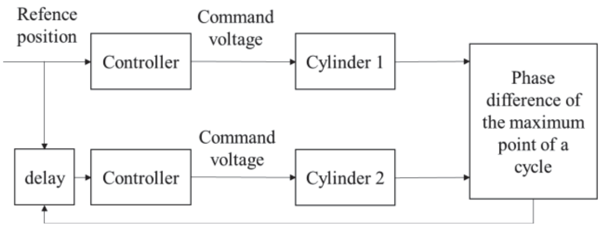

Fig. 2 Phase feedback control algorithm

3. Controller verification

3.1 Experimental setup

Fig. 3 shows the pneumatic fatigue tester testbed constructed for performance verification of the developed controller. A pneumatic cylinder with a stroke of 100 mm and a maximum load of 10 kN was used, and pressure was applied to the pneumatic cylinder based on the controller output signal in analog voltage format using a valve system (3/8, Festo). To measure the position of the pneumatic cylinder end effector, an LVDT (SDAT-100, Festo) with a measuring range of 100 mm and a resolution of 10 µm was applied. To measure the load applied to the specimen, a load cell (DSCS-1000, Bongshin) with a maximum measurement value of 10 kN and a resolution of 1 N was used. A pneumatic regulator (MS4-LFR-1/4-D7-ERM-AS, Festo) was installed for stable control of the pneumatic cylinder, and the target pressure was set to 6 bar. Based on the proposed control algorithm, a controller for pneumatic fatigue testing machine was made. Considering the real-time performance of the controller and the compatibility with the pneumatic fatigue tester test bed, National instrument sbRIO (sbRIO-9637) was used.

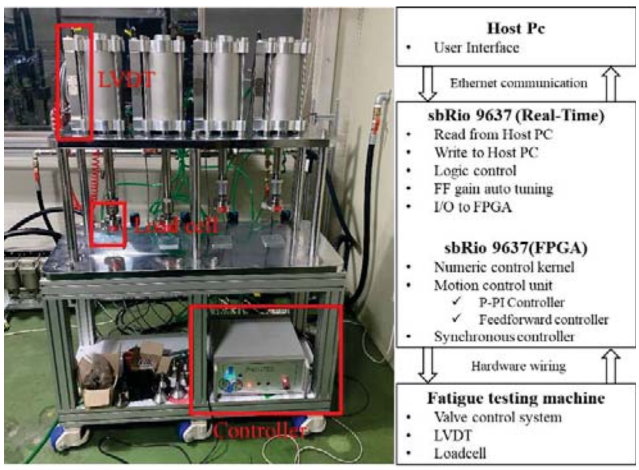

Fig. 3 Multi-axis pneumatic fatigue tester

Table 1 Max synchronous errors at various conditions

Control target	Amplitude	Frequency	Synchronous error
Position	10mm	5hz	0.14 mm
Load	2000N	5hz	34.49 N
	18000N	1hz	119.73 N

3.2 Controller verification

Table 1 is the result of position synchronous control and load synchronous control. position control and load control were performed at a speed of 5 Hz, and an experiment was performed at a load control of 1 Hz in order to confirm the accuracy at a low frequency. The tests were performed for 1000cycles. Synchronization error is the maximum difference between the master cylinder value and the slave cylinder value during one cycle. The table showed the highest values during 1000 cycles.

In position control, the initial position was set to 75 mm and controlled to a sine wave of 10 mm. As a result of synchronous control, the synchronous error between the master axis and the slave axis converged to around 1.5%.

In load control, the initial load was set to 0 N and controlled to a sine wave of 2000 N. As a result of synchronous control, the synchronous error of the master shaft and the slave shaft converged to around 1.5%.

In the low-frequency load control, the initial load was set to 0N and controlled to a sine wave of 18000 N. As a result of synchronous control, the synchronous error between the master axis and the slave axis converged to within 1%.

4. Conclusion

In this study, a control algorithm for synchronous control of the position and load of a pneumatic cylinder was proposed, and its performance was confirmed by applying it to a fatigue tester. An algorithm to improve the control performance by checking the state of the cylinder and giving a delay to the command of the slave axis was proposed. By synchronous control of position and load at various amplitudes and frequencies, it was confirmed that synchronization errors of 1.5% for high-frequency position control and 1.5% for high-frequency load control and 1% for low-frequency load control were obtained by the proposed algorithm.

ACKNOWLEDGEMENT

This work was supported by the Technology Development Program in Manufacturing Equipment (20012834, Development of Smart CNC Control System Technology for Manufacturing Equipment) funded By the Ministry of Trade, Industry & Energy(MOTIE, Korea)

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