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REPEATED POSITIONING OF A LONG STROKE PNEUMATIC CYLINDER USING PROXIMITY SWITCHES

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ABSTRACT

This paper deals with a technique of repeated positioning of a long stroke pneumatic cylinder. This system is suitable for a long stroke cylinder when the desired intermediate stop positions are fixed and the same operation may be repeated as in automatic production lines. The basic control algorism is a sequential on-off action of the air valves. For one desired position, three proximity switches are installed to detect the slider passing as well as its velocity. The main experimental result with a rod-less cylinder of 1000 mm stroke is that the control accuracy converged quickly within +/-0.2mm by a learning function.

KEY WORDS

Pneumatic, Cylinder, Positioning, Proximity switch, Learning

INTRODUCTION

This paper deals with a technique of repeated positioning of a long stroke pneumatic cylinder. This system is suitable for a long stroke cylinder when the desired intermediate stop positions are fixed and the same operation may be repeated as in automatic production lines.

The design of an air servo system is not intended. Without constructing a feedback loop, it is possible to maintain the simplicity of the air positioning system.

The basic control algorism is a sequential on-off action of directional air valves. There is a fact that a clear relationship exists between the slider velocity and its braking distance with a strong braking [1]. For one desired position, three proximity switches are installed to detect the slider passing as well as its velocity. After passing the first switch the slider is weakly decelerated, and after passing the second switch it is strongly decelerated. The third switch is installed to detect the final positioning result which is used in the next run by a learning scheme [2]. Another switch is also installed to confirm the slider return to the starting point.

As a matter of course, the positioning accuracy depends strongly on the frictional condition. There is another factor such as the load or the setting direction of the cylinder. In the experiment, the cylinder was set in vertical direction to reveal the effect of the slider load.

A high positioning accuracy can not be expected without a feedback loop. Our final goal is that the stop position converges to the desired region in several operations and that the accuracy can be kept after that.

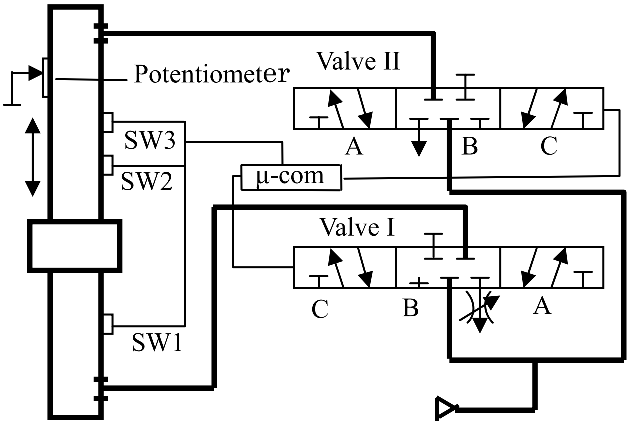

Figure 1 Experimental circuit

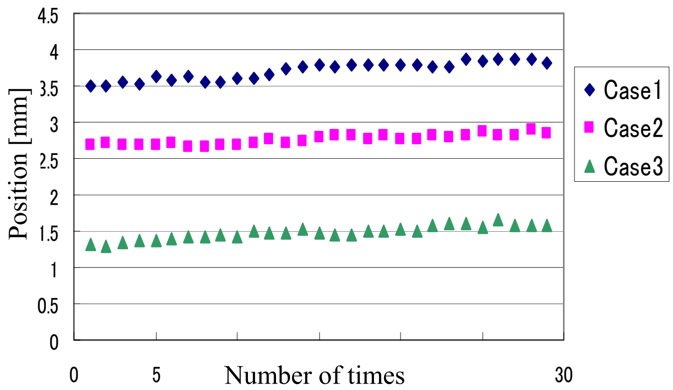

Figure 2 Deviation of the stop position

EXPERIMENTAL APPARATUS AND THE POSITIONING METHOD

Pneumatic circuit

The outline of experimental apparatus is shown in Fig. 1. The cylinder is installed vertically on the wall in a laboratory. The cylinder is of a rod less magnet type and has a stroke of 1000mm in length and a bore of 40mm in diameter.

Four proximity switches are installed. SW1, SW2, SW3 are used for motion control, and SW0 is used only for detecting the return of the slider to the starting point (not shown in the figure).

For the cylinder positioning, we propose a two-stage braking method, which will be described later in detail. In this method, a weak braking and a strong braking are applied in sequence.

At the first stage, weak braking is applied, and strong braking is applied in the second stage. To apply the weak braking, the valve I is kept on connecting to supply port and only the valve II is closed. To apply strong braking, the valve I is still kept on connecting to the supply port and the valve II is switched to the supply port.

To perform this sequence smoothly, two 3-position 5-port valves are utilized for changing the air flow.

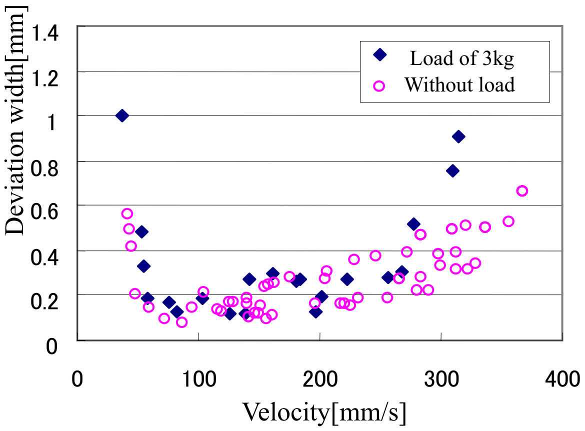

Figure 3 Optimum velocity to start applying the strong braking

Fluctuations of the stop position

It is a necessary condition for our method that fluctuations of stop position are small even when the two-stage positioning is not applied.

Fig.2 shows the result of the slider stop position in a case that the strong braking was applied simultaneously when it passed through the SW2. The cases of 1, 2, 3 mean that the SW2 passage velocity was changed by the timing of weak braking after passing of the SW1.

The experiments were done continuously 30 times respectively. This figure indicates that during the prolonged operations, the fluctuation in every successive two trials is only about 0.1mm. This amount is small and is not a problem because it can be corrected during the operation. Therefore, the possibility to continuing the operation with maintaining accuracy was confirmed.

Furthermore, Fig.3 shows the relationship between the velocity that the strong braking was started to apply and the deviation of the braking distance. The axis of ordinate is not showing the stop position but the deviation width of the stop positions. One dot indicates deviation width in twenty times operation conducted.

In this experiment, the SW2 passage velocity was also changed due to the weak braking applied at the SW1.

There is an optimal velocity when the braking should be started to apply, and it was about 100mm/s in this case.

Even if it loaded a mass of 3kg, there is no difference in the optimum value.

When the same cylinder was installed in horizontal direction, the value showed 220 - 250 mm/s [1,2].

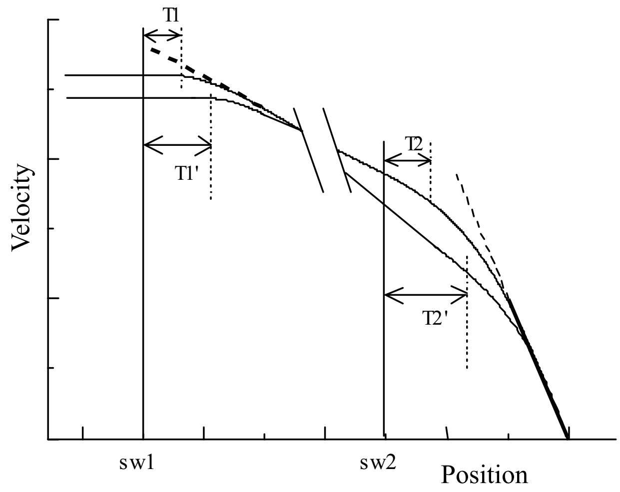

Figure 4 Two-stage braking

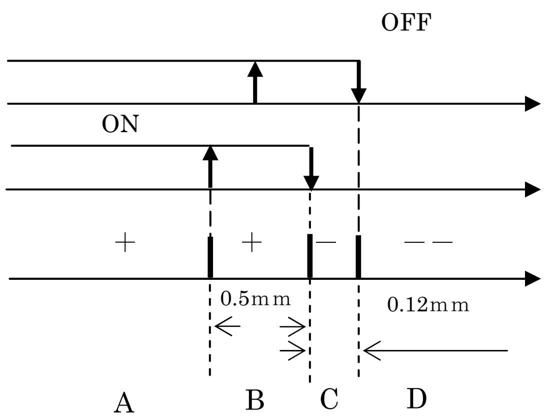

Figure 5 Shifting of the sensing position

Positioning method

The outline of the two-stage braking method is shown in Fig. 4. At first, the timer length $T1$ to start applying the weak braking is determined based on the passage velocity on the SW1, so that the slider velocity might become the above-mentioned optimal value at the SW2. Next, the timer length $T2$ to start applying the strong braking is calculated depending on the detected passage velocity on the SW2 so as to stop the slider at the desired position.

Fig. 5 explains the role of the SW3 equipped in order to check the final stop position. It is impossible to detect the stop position in accuracy of 0.1mm because sensing width of an ordinary proximity switch is 3-4mm. Therefore, a small coil was added to the side of the switch to affect the neighboring magnetic field. The sensing position was shifted about 0.12mm as shown in Fig.5. The hysteresis width of the sensor was also used.

The hysteresis and sensing positions of the tested proximity switch when the coil current is turned off and on are illustrated in Fig.5. By turning the coil current off and on, the sensing field is divided into 4 regions, A, B, C, D. The boundary of B and C in the figure was determined as the target position.

In each operation, the detected data are used to update the control parameters of the timer T2 by a learning algorism. In an ideal condition, the slider stops in very narrow region near the boundary of B and C, and every stop position falls into B and C region alternately.

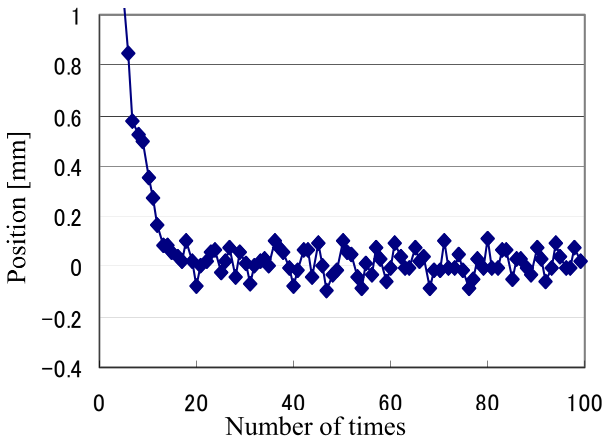

Figure 6 Convergence of the stop position

EXPERIMENTS OF REPEATED POSITIONING

Setting of timer T1 and T2

The equations to obtain the timer length $T1$ and $T2$ are as follows;

$$T1 = a1 \cdot (Count\_1 - b1) + c1 \quad (1)$$

$$T2 = a2 \cdot (Count\_1 - b2) + c2 + \Delta y \quad (2)$$

where $a1, b1, c1, a2, b2, c2$ are constants, and $Count\_1, Count\_2$ are the counted numbers in the program for the passage time on the SW1 and the SW2,respectively, and Δy is a quantity to be modified for the next operation.

Although $T1$ and $T2$ need to be changed when the cylinder is modified from the horizontal to vertical direction or when another cylinder is used, the minimum change was tried; only the parameter $c2$ was readjusted from our experiences. When the parameter $c2$ was not changed, the controller could not deal with new direction of the cylinder. The value of $c2$ was estimated by preliminary experiments.

For the check of the modifying process, the relation between the stop position and the timer length $T2$ was recorded. The feature of convergence of the stop position is shown in Fig.6. It converged after about 20 times using the data of the position information on the SW3, as well as $Count\_1$ and $Count\_2$.

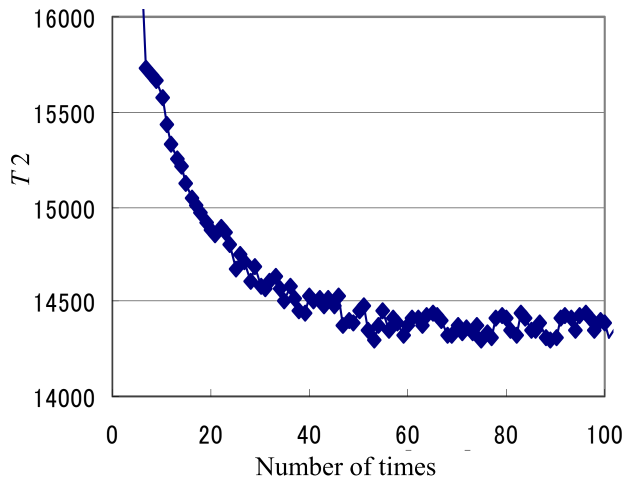

Figure 7 Convergence of the timer length $T2$

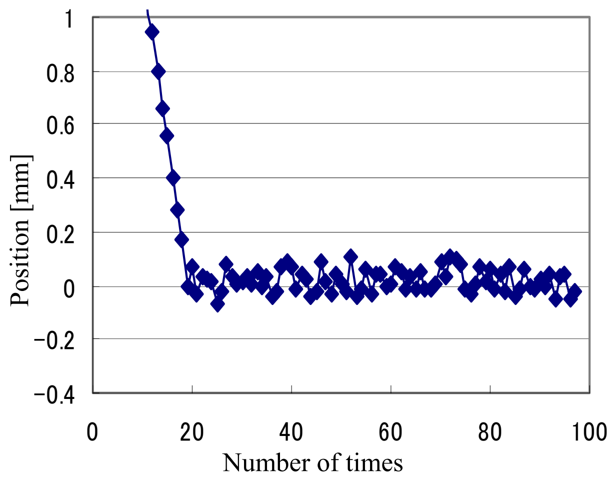

Figure 9 Adjustment of $a2$ and Δy ($a2$=4, Δy=32)

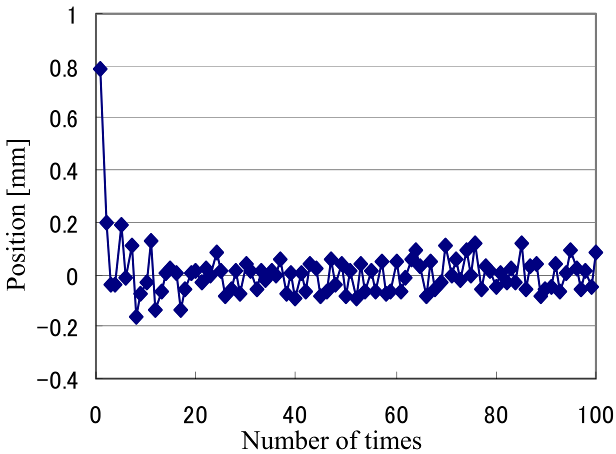

Figure 8 Adjustment of $a2$ and Δy ($a2$=3, Δy=48)

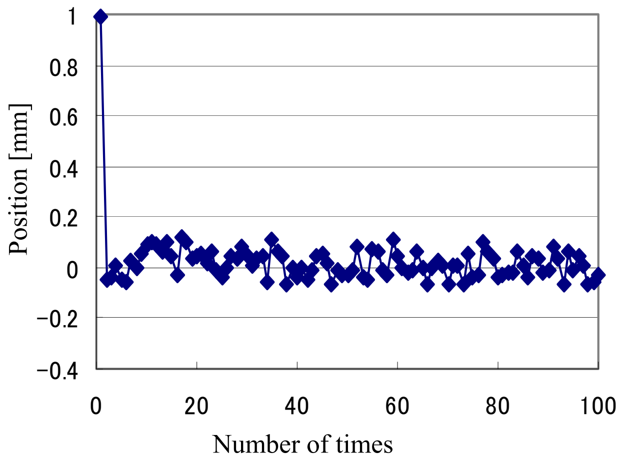

Figure 10 Convergence of the stop position with loading a mass of 3kg

Fig. 7 shows that $T2$ converged after about 50 times using the position information on the SW3. We will discuss later about $a2$ and Δy. There is no necessity to change $b1$ and $b2$ because they are only used in checking if the $Count\_1$ or $Count\_2$ are too short.

Fine Tuning of Timer T2

Fine tuning of the timer $T2$ rather than $T1$ leads to the improvement in the positioning accuracy. It is because the distance between the SW3 and the stop position is as near as about 30mm. Since approximate values of $a2$ and Δy in equation (1) have been also obtained from preliminary experiments, here we will examine about the constant $a2$. During the usual operation, the value of $a2$ is fixed, while the value of Δy is added or subtracted in every operation.

Fig.8 and Fig.9 are the results of comparing the influence on the values of $a2$ and Δy.

Good results were obtained with the combination of $a2$= 3; Δy =48, or $a2$ =4; Δy =32. They were conducted with no load.

When the slider was loaded with a mass of 3kg and the parameters was $a2$ =4 and Δy =32, accurate positioning was also good as shown in Fig.10.

REDUCTION OF INITIAL DEVIATION

In this positioning method, the purpose to stop at a target position accurately from the beginning of operation is not expected, and we are satisfied if stop position can converge to the target position after several operations.

However, the less number of operations to converge is the better. Because of it, a means to reduce the initial deviation should be considered.

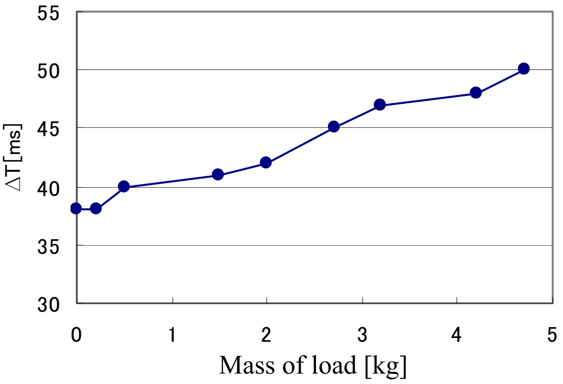

Figure 11 Relation between mass of load and SW2 secession time

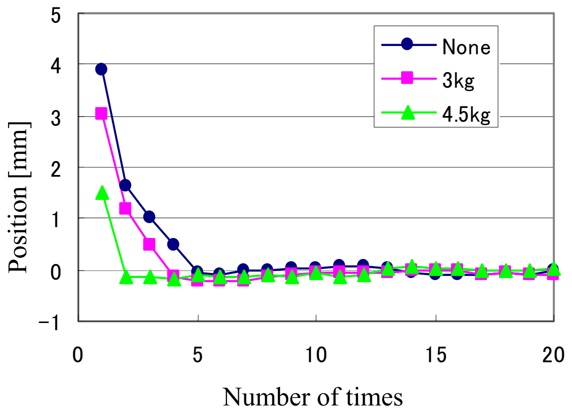

Figure 12 Effects of loaded mass on the stop position

Since the initial deviation is largely caused by the value of $c2$, an automatic adjustment of $c2$ should bring a good result.

SW0 secession time and stop position

As an information factor to be defined, there is a time length between the moments when the slider starts to move upward and when it secedes from the sensing range of SW0. ΔT is determined as this time length. Fig.11 shows the measured ΔT for various mass of loads. Acceleration will take longer time due to the increasing of mass of load. As a result, ΔT becomes larger.

By the difference of magnitude of load the initial stop position was changed as shown in Fig.12. It was predicted that the stop position will be ahead of the target position due to inertia but the result was opposite. This could be explained that the slider velocity became slower caused by the increasing load. After the second time, the stop position converged by this $\Delta T : c2$ adjustment scheme.

Adjustment of T2 by SW0 secession time

The cause of deviation cannot be specified only by the value of ΔT. The change factors are not only the load but also the supply pressure, and they effect in opposite results on the stop position. In the following, the supply pressure is assumed to be known and a scheme will be investigated to rectify the initial deviation owing to the change of load.

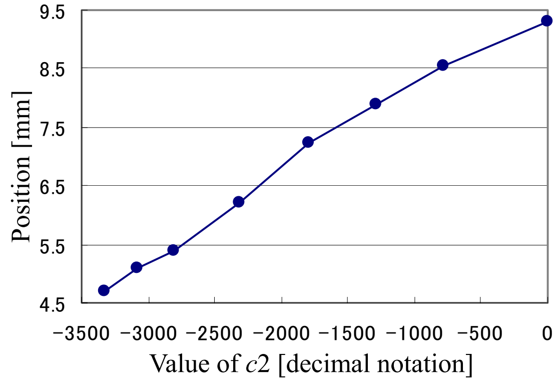

Figure 13 Relation between $c2$ and the stop position

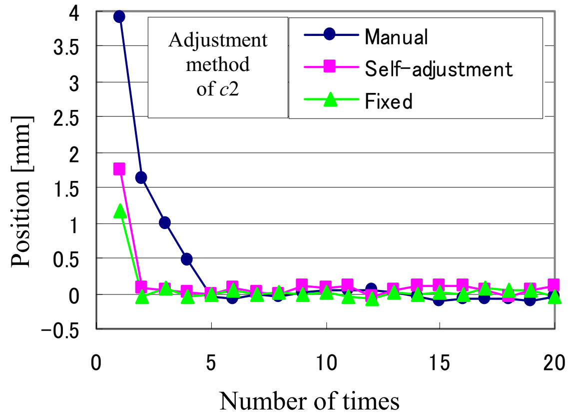

Figure 14 Adjustment of $c2$ with no load

Fig.13 shows the observed result of the initial stop positions. This was obtained by repeated experiments when the value of $c2$ in $T2$ was varied, and only each first positioning was measured and plotted.

Here, using Fig.11 and Fig.13, we consider the approximate first-order equation relating ΔT and $c2$. Our attempt is to adjust $c2$ using ΔT only at the first operation. After the second operation, the stop position will converge by modifying $T2$ with Δy.

Fig.14 indicates the effect of $c2$ adjustment with no load condition. In the figure, "Manual" means that $c2$ was adjusted from experience, and "Self-adjustment" means that it was adjusted automatically using the first value of ΔT. On the other hand, "Fixed" means that $c2$ was set without consideration of the operating condition. Although there is still deviation at the first time even when using the self adjustment, the positioning was improved in number of times to converge as compared to Fig.6-Fig.10.

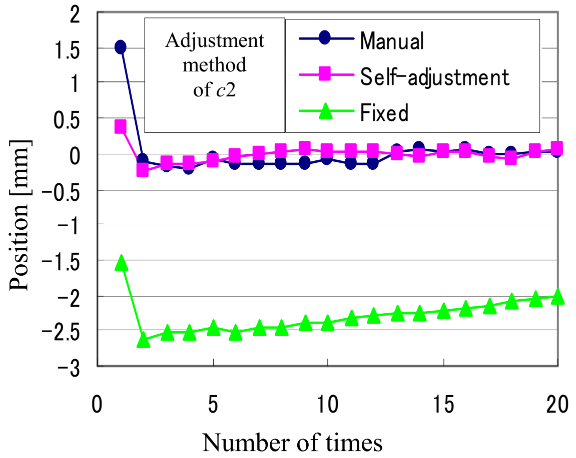

Figure 15 Adjustment of $c2$ with a mass-load of 4kg

Fig.15 shows the positioning results when the load was increased to 4.5kg. With the fixed value of $c2$, the initial stop position deviated far away from the desired position. After that, a great number of times were needed to recover to the desired position.
By using "self-adjustment of $c2$", the initial deviation became smaller regardless of the load. After the second operation, fairly good convergence was achieved.
Fig.16 demonstrates the effect of "self-adjustment of $c2$", where the magnitude of load has not been input into the program. Because vertical axes in figures are in different scale, there are difficulties in comparing with others. Nevertheless it can be seen that the positioning accuracy was sufficiently maintained within +/-0.2mm.

CONCLUSIONS

The experimental results on the repeated positioning of a long stroke pneumatic cylinder using proximity switches are summarized as follows.
1) The cylinder was installed in the vertical direction and the positioning accuracy by the existence of load was investigated. With the cylinder stroke of 1000mm, the slider could stop enough in the range of +/-0.2mm, and the accuracy has been maintained also in the following prolonged operation.
2) The timing which finally applies strong braking is the most important, and it turned out that what is necessary is just to perform the timer adjustment according to the operating conditions such as the slider load.

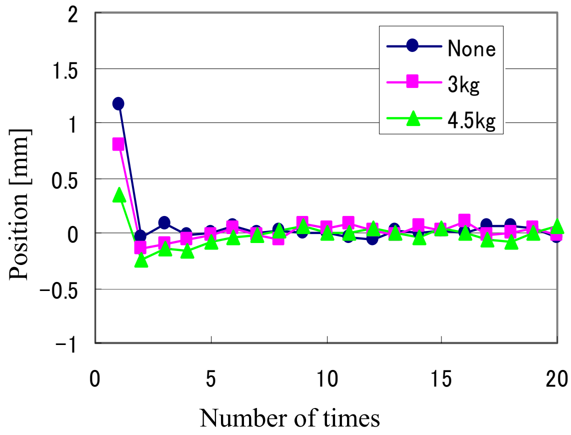

Figure 16 Effect of the self-adjustment of $c2$

3) The technique of decreasing the initial deviation based on the secession time of the switch installed in the starting point is expected to have sufficient effect when other conditions, for example, the supply pressure, are constant.
Our future work is to improve the system performance to keep a sufficient accuracy from the first operation by automatically adjusting the control timer according to the change of conditions.

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