論文 / 著書情報
Article / Book Information

題目(和文)	空気圧人工筋肉を用いた精密システムの簡単なコントローラ設計と特性評価
Title(English)	Simple Controller Design and Characteristic Evaluation of Precision Systems with Pneumatic Artificial Muscles
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Category(English)	Doctoral Thesis
種別(和文)	論文要旨
Type(English)	Summary

（博士課程）
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論 文 要 旨

THESIS SUMMARY

専攻： Department of	メカのマイクロ工学　専攻	申請学位（専攻分野）： Academic Degree Requested	博士 Doctor of　（　工学　）
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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

In this thesis, a simple controller design method for precision motion of pneumatic artificial muscle (PAM) mechanisms was proposed and its usefulness was examined experimentally. Then using the designed controller, the energy consumption and the thermal phenomenon of the PAM mechanism in this research were evaluated. The summary of the thesis is shown as follow.

(1) The simple controller design method for precision motion of PAM mechanisms was proposed and its usefulness was examined experimentally.

In this research, a mover connected to a pair of Mckibben PAMs in the antagonistic structure is used as the experimental setup since this structure is widely used as a basic driving unit in PAM mechanisms. In order to achieve the precision motion control of the PAM mechanism, at the first step, the simple controller design method for precision point-to-point positioning was proposed. Using a controller switch algorithm the transient response in positioning is controlled by an open-loop controller, and then after the mover of the mechanism arrived at a target position, the mechanism is controlled by a closed-loop controller designed for reduction of residual vibration. In the closed-loop controller design, nonlinear compensators are constructed easily from the open-loop responses without modeling. After that, conventional control elements such as a PID and an acceleration feedback elements are determined. The positioning results show that sub-micrometer (0.9 μm; 0.09 % of the step range from 0 mm to 1mm) positioning accuracy and 0.5 μm positioning resolution were achieved. However, residual vibrations in the range of 5~20 Hz were observed. This vibration limited the positioning accuracy.

In order to reduce the residual vibration, microscopic characteristics of the PAM mechanism were experimentally examined. The experimental results indicate that the mechanism shows the significant phase-delay characteristics in microscopic region. According to the characteristics, a phase-lead element was designed to compensate the phase-delay characteristic, and the positioning controller was improved. The positioning results indicate that the designed controller reduced the maximum amplitude of the residual vibration from 0.9 μm to 0.7 μm (0.07 % of the step range from 0 mm to 1mm). Next, in order to achieve precision motion control, the inverse model of a 1st-order system was

adopted and a simple modified feed-forward element (SM FF element) was constructed to the control system for precision motion control. The tracking results indicate that the maximum tracking errors were less than 2 and 5 μm (0.04 % and 0.1 % of the tracking range from 0 mm to 0.5 mm) under 0.1- and 0.5-Hz sinusoidal tracking control, respectively. Although the control system with the SM FF element gives larger overshoot than the first designed control system, the problem of the overshoot in positioning could be solved using a suitable step-like reference.

According to the conclusions shown above, the designed controller provides precision motion of the PAM mechanism. The positioning accuracy is on the order of sub-micrometer, and the tracking accuracy is on the order of micrometer.

(2) Using the designed controller for precision motion of PAM mechanisms, the energy consumption and the thermal phenomenon has been evaluated.

a. Energy consumption

The electrical energy for driving the servo valve and the air energy from the pressure supply in the mechanism were calculated using measured responses. The mechanical work done by the two PAMs and the amounts of energy loss caused by the friction between the guide and the mover, the damping and the spring elements were calculated using a conventional dynamic model of the PAM mechanism. According to the calculated and measured results, it was found that most of the energy source is air energy, but only less than 0.05 % of the energy source is transferred to the energy related to the motion. According to comparison to electric motor, it is known that the efficiency of the PAM mechanism is very low (< 0.005 % in the experimental conditions). The reason of low efficiency is that there is approximately 90 % of the air energy lost by air leakage. These results suggest that the achievement of a low air leakage valve is the subject for improving the energy efficiency of PAM mechanisms. If it can be achieved, the energy efficiency can be enhanced significantly.

b. Thermal phenomenon

Using the thermography, the temperatures of the atmosphere, the PAMs, mechanical parts of the PAM mechanism were measured during the precision motion control in different motion conditions. According to the measured results, it was found that the temperature rise of the PAM mechanism depends on motion frequency and amplitude. When the amplitude became double, the temperature rise became more than doubled. When both the amplitude and the frequency doubled, the temperature rise became more than tripled. Comparing the air energy consumption and motion accuracy between before and after 20 minutes motion control, there was no significant difference.