

PERPUSTAKAAN UMP



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**Developmen** **low-cost**  
**Wearable Servo valve using Duckled Tubes**  
**and Embedded Controller**

**2016**

Okayama University of Science  
Graduate School of Engineering  
Systems Science

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## NOTATION

- $A_i$  : Sectional area of buckled tube [ $\text{m}^2$ ]
- $b_T$  : Damping coefficient of disc with buckled tubes [ $\text{Nm}/(\text{rad/s})$ ]
- $D_Z$  : Duty ratio corresponding to the dead zone of the valve [%]
- $duty(i)$  : Input duty ratio to the RC servo motor [%]
- $e(i)$  : Deviation of the displacement from the desired position [mm]
- $e_p(i)$  : Pressure deviation from the desired pressure [Pa]
- $i$  : Motor current [A]
- $J_M$  : Servo motor inertia moment [ $\text{kg}\cdot\text{m}^2$ ]
- $k_e$  : Reverse electromotive force constant [Vs/rad] |πd|
- $K_D$  : Differential gain for positioning control of rubber artificial muscle [%·s/mm]
- $K_{DP}$  : Differential gain for pressure control [%·s/kPa]
- $K_p$  : Proportional gain for positioning control of rubber artificial muscle [%/mm]
- $K_{pp}$  : Proportional gain for pressure control [%/kPa]
- $L$  : Dead time of servo motor [s]
- $L_M$  : Internal inductance of servo motor [H]
- $P_a$  : Atmosphere pressure [Pa]
- $P_o$  : Output pressure of the valve [Pa]
- $P_s$  : Supply pressure of the valve [Pa]
- $Q_a$  : Exhaust flow rate of the valve [kg/s]
- $Q_s$  : Supply flow rate of the valve [kg/s]
- $R$  : Gas constant [ $\text{J}/(\text{kg}\cdot\text{K})$ ]
- $R_M$  : Internal resistance of servo motor [ $\Omega$ ]

$r_T$  : Distance from the central axis of the motor to the fixed point of the right/left tube [m]

$r_{Ti}$  : Distance from the tube buckling point to the tube holding point [m]

$T$  : Absolute temperature [K]

$u(i)$  : Control input [%]

$V_{cc}$  : Supply voltage to servo motor [V]

$V_M$  : Applied voltage to servo motor [V]

$V_o$  : Volume of the tank [ $\text{m}^3$ ]

$W_T$  : Distance from the motor axis to the buckling point of left/right tube [m]

$\theta$  : Motor rotational angle [rad]

$\theta_{i0}$  : Initial angle of buckled tube from motor shaft [rad],

$\theta_r$  : Target angle of motor [rad]

$\theta_{Ti}$  : Buckling angle of buckled tube [rad]

$\kappa$  : Air specific heat ratio [-]

$\rho$  : Atmospheric density [ $\text{kg}/\text{m}^3$ ]

$\tau_M$  : Generated torque of the motor [Nm]

$\tau_{Mi}$  : Restoration torque at motor shaft given by restoration torque of buckled tube [Nm]

$\tau_{MV}$  : Motor torque corresponding of  $K_M \cdot V_M/R_M$  [Nm]

$\tau_{Ti}$  : Torque generated by the restoration force from the buckled tube [Nm]

$\Delta T$  : Sampling period [s]

Here, suffix "i" in certain equations will indicate "L" and "R" that mean left and right, respectively. Then, 0 indicates the initial value.

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## Abstract

In this study, a small-size, lightweight and low cost servo valve is developed to replace the typical solenoid valve. As an inexpensive method of changing the opening area of the valve, the method of changing the buckling condition of the tube using a RC servo motor is proposed. 3-port twisting type valve is also proposed and tested to adjust its supply and exhaust states at the same time. In order to decrease its non-linear characteristics in relation between output flow rate and motor rotational angle, a new 3-port bending type servo valve that has smaller hysteresis characteristics and smaller overlap zone is proposed. Furthermore, position control of rubber artificial muscle using twisting and bending type valve are carried out. As a result, the standard deviation of positioning errors using bending type valve is improved from 2.0 mm to 0.9 mm. Also, pressure controlled type servo valve is proposed. By using bending type valve with smaller dead zone, the dead time of the valve is decreased. From the pressure tracking control result, the improved bandwidth frequency of 4.1 Hz was obtained compared with the previous pressure controlled twisting type valve that is 2.2 Hz. Therefore, the validity and better performance of bending type valve was confirmed. For optimal design of the valve, an analytical model of the valve with embedded controller is proposed. The system parameters are also identified. Especially the relations between the buckling angle with respect to the restoration torque and the tubes opening area are assumed as empirical formula from experimental results. In order to confirm the validity of the proposed model and identified parameters of the valve, the calculated statics and dynamics behaviors of the valve model is compared with the experimental results. It is obtained that the calculated results using the model agree well with the experimental results. It can be concluded that the proposed model and identified parameters are useful to estimate the performance of the valve by changing the arrangement of two buckled tubes. Moreover, in order to obtain the optimal arrangement of buckled tube, the calculation results of pressure tracking control performance using the valve with various arrangements of two buckled tubes is carried out. Thus, the optimal design parameter of buckling point and the initial buckled angle of tubes and optimal control gain can be obtained. Based on the calculated transient response of tracking pressure using the optimal values, it can be confirmed that the valve performance with optimal design parameters can be theoretically improved.

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