

## Control of the Pneumatic Actuator with McKibben Artificial Muscles

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**Abstract:** *The pneumatic actuator based on McKibben artificial muscles in antagonistic connection was designed and realized. The artificial muscles are acting against themselves and resultant position of the actuator is given by equilibrium of their forces according to different pressures in muscles. The pressures in artificial muscles (and in this manner muscles contraction too) are controlled by four solenoid valves (two for muscles filling and two for emptying). On the theoretical and experimental basis the block diagram for position control of the actuator arm (with possible slave velocity control loop) was designed. The new algorithm based on simultaneous pressure control only in one muscle was designed too. This algorithm reduces requirements for control of such pneumatic actuator.*

**Keywords:** *pneumatic actuator, artificial muscle, control*

### 1 Introduction

The pneumatic actuator based on two McKibben artificial muscles in antagonistic connection was created as result of research projects solved on the author's workplace (Figure 1). The muscle contraction (and muscle tension force too) depends on the compressed air pressure and period of air flow into the muscle. The artificial muscles are acting against themselves and resultant position of the actuator is given by equilibrium of their tension forces according to different pressures in muscles. Two solenoid valves (one for filling and one for emptying) are needed for operating of one muscle.



Figure 1 – Pneumatic actuator with artificial muscles

## **2 Philosophy of control of the pneumatic antagonistic actuator**

Current control of the pneumatic antagonistic actuators is realized by pressure increasing in the one artificial muscle and simultaneous pressure decreasing in the other (antagonistic) artificial muscle. In this case both artificial muscles are active and they require simultaneous pressure control in both muscles. That is difficult for control because the equilibrium condition between air pressure (volume) increment in the one artificial muscle and air pressure (volume) decrement in the other artificial muscle has to be executed. Otherwise the non-uniform movement of the actuator arm can occur.

With the aim of control simplification the control philosophy of the pneumatic antagonistic actuator was designed with different operation of the pneumatic artificial muscles. The one of the artificial muscles subserves as non-linear pneumatic spring at appropriate half of actuator arm path and it needn't any control action. The only other antagonistic artificial muscle (active) is controlled at this appropriate half of actuator arm path and its movement and position are controlled by air pressure control. At the other half of actuator arm path the operation of actuator is the same, but the function of the muscles is replaced.

Two-position solenoid valves operate contraction of the pneumatic artificial muscles. The compressed air is supplied into artificial muscle through the valves in the form of pressure impulses. The emptying of muscles is done in this manner too. For all that it is necessary to consider with these facts for design of actuator arm position control:

- Pneumatic artificial muscle (and pneumatic actuator with artificial muscles too) is non-linear system with dead zone and non-linear static characteristic with saturation.
- Dynamic characteristics of the pneumatic artificial muscle are comparable to linear oscillating element. Damping, time constant and gain are dependent on material properties, dimensions and load of artificial muscle.
- Volume of artificial muscle is operated by pressure impulses through solenoid valves. Their characteristics are relay non-linearity. The input actuation signals of the valves are binary signals variable in the form of discrete steps.
- The manipulated variable of the system (pressure or volume of compressed air) is transferred into artificial muscle with time delay.

The facts listed above have to be respect by design of control of such system. The main requirement for operation of the pneumatic actuator is uniform movement and accurate arm position control according to input desired variable. Some variables in system will be of discrete or impulse character.

## **3 Structure of position control of the actuator arm**

On the base of analyze of existing solutions and experiences of servo systems design and operation this conception was designed for position control of the pneumatic antagonistic actuator:

- The main and sometimes the only one controlled variable will be actuator arm position.
- The stiffness of the arm position should be maximally achievable and self-aligning under given conditions. Assurance of the previous condition assumes using of maximal air pressure allowed for used type of artificial muscle.
- The actuator arm will be at the reference point (zero point) after filling of both muscles by air to maximal pressure. The stiffness will be maximum and bilateral symmetric at this point. The movement of the actuator arm from this point in the positive or negative direction will be done by emptying of appropriate muscle. The stiffness of the actuator will decrease according to muscles characteristics but it will be higher or equal than by present solution of actuator control.



actuator arm turning to the right or left is generated ( $R/\bar{L}$ ). Decoder ( $D$ ) determines which solenoid valve of the actuator will be operated. The manipulated signals for solenoid valves ( $ABCD$ ) are gained by power block containing the transistor power switches. By signal “set” ( $SET$ ) the actuator arm is setting to the reference position (artificial muscle AM1 and AM2 are filled to maximal pressure). By signal “out” ( $OUT$ ) the muscles disconnect from compressed air supply and the air is discharging from muscle. The actuator movement can be operated by manual control too.

#### 4 Block diagram of control

The block diagram of arm position control of the pneumatic antagonistic actuator was designed on the basis presented above (Figure 3):

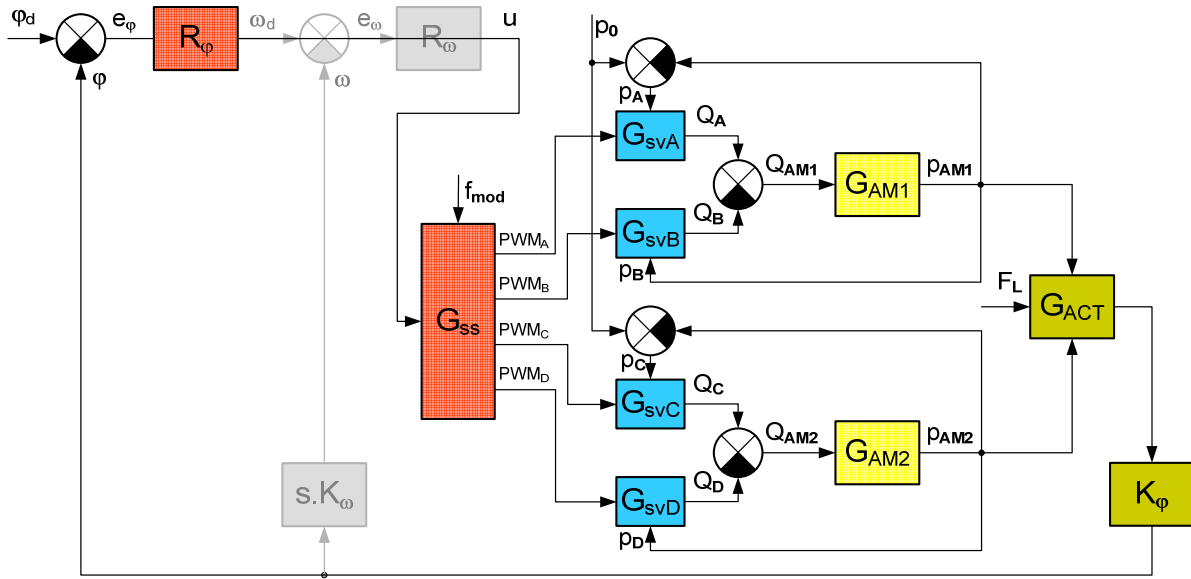


Figure 3 – Block diagram of position control of the actuator arm

The variables and blocks in block diagram on Figure 3:

- $\varphi_d$  – desired variable of the actuator arm position,
- $\varphi$  – actuator arm position,
- $e_\varphi$  – control deviation of the desired and actual value of the actuator arm position,
- $R_\varphi$  – transfer function of the position controller,
- $\omega_d$  – desired variable of the actuator arm velocity,
- $\omega$  – actuator arm velocity,
- $e_\omega$  – control deviation of the desired and actual value of the actuator arm velocity,
- $R_\omega$  – transfer function of the velocity controller,
- $u$  – manipulated variable,
- $s$  – Laplace operator,
- $K_\varphi$  – transfer function of the position sensing unit,
- $K_\omega$  – gain of the velocity sensing,
- $f_{mod}$  – modulation frequency,
- $G_{ss}$  – transfer function of the signal shaper,
- $PWM_A, PWM_B, PWM_C, PWM_D$  – pulse width modulated signals for control of solenoid valves,
- $p_0$  – compressed air supply pressure,

$p_A, p_B, p_C, p_D$  – air pressure for solenoid valves,  
 $G_{svA}, G_{svB}, G_{svC}, G_{svD}$  – transfer functions of the solenoid valves,  
 $Q_A, Q_B, Q_C, Q_D$  – air flow through the solenoid valves,  
 $Q_{AM1}, Q_{AM2}$  – air flow into the artificial muscles,  
 $G_{AM1}, G_{AM2}$  – transfer functions of the artificial muscles,  
 $p_{AM1}, p_{AM2}$  – pressure in the artificial muscles,  
 $G_{ACT}$  – transfer function of the actuator arm,  
 $F_L$  – load force.

## 5 Conclusions

The designed algorithm based on simultaneous pressure control only in one muscle reduces requirements for control of the pneumatic actuator with McKibben artificial muscles. Actuator arm position is controlled simultaneous only by one solenoid valve (by filling or emptying valve of the only active artificial muscle). The passive artificial muscle has a constant pressure and it acts as non-linear pneumatic spring. The stiffness of the actuator is self-aligning and maximal for appropriate arm position.

The controller can be realized on the base of microcomputer chip or on the base of personal computer with I/O card. Nowadays the algorithm is realized and tested by Real Time Toolbox of Matlab Simulink and I/O card. The first results of testing confirmed the right approach to a design of control of the pneumatic actuator with artificial muscles in antagonistic connection.

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