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CONTROL OF THE ACTUATOR WITH PNEUMATIC ARTIFICIAL MUSCLES IN ANTAGONISTIC CONNECTION

RIADENIE AKTUÁTORA S PNEUMATICKÝMI UMELÝMI SVALMI V ANTAGONISTICKOM ZAPOJENÍ

Abstract

The actuator based on pneumatic artificial muscles in antagonistic connection was designed and realized on the author's workplace. The pneumatic 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 actuator.

Abstrakt

Aktuátor na báze pneumatických umelých svalov v antagonistickom zapojení bol navrhnutý a zrealizovaný na pracovisku autorov. Pneumatické umelé svaly pôsobia proti sebe, pričom výsledná poloha aktuátora je daná rovnováhou ich ťahových síl v závislosti na rôznych tlakoch vo svaloch. Tlaky vo svaloch (a tým aj kontrakcia svalov) sú riadené pomocou štyroch solenoidových ventilov (dva pre plnenie svalov a dva pre vyprázdňovanie svalov). Na základe teoretických východísk a realizovaných experimentov bola navrhnutá bloková schéma riadenia polohy ramena aktuátora (s možnosťou podriadenej rýchlostnej slučky). Taktiež bol navrhnutý nový algoritmus riadenia aktuátora založený na súčasnom riadení tlaku iba v jednom svale. Tento algoritmus znižuje nároky na riadenie takéhoto aktuátora.

1 INTRODUCTION

The actuator based on two pneumatic artificial muscles in antagonistic connection was created as result of research projects solved on the author's workplace (Fig. 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. The two solenoid valves (one for filling and one for emptying) are needed for operating of one muscle.

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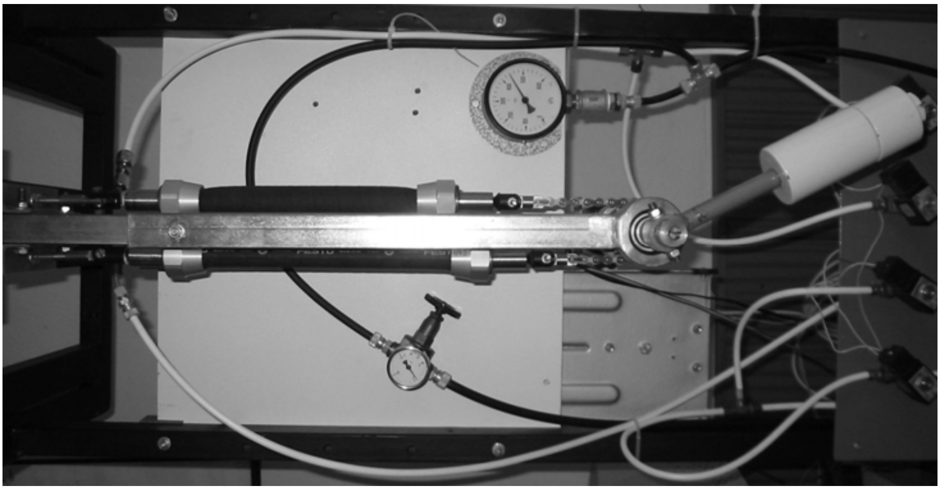

Fig. 1 Experimental actuator with pneumatic artificial muscles in antagonistic connection

2 PHILOSOPHY OF CONTROL OF THE ACTUATOR

Operation of the present actuators with pneumatic artificial muscles 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 actuator was designed with different operation of the pneumatic artificial muscles. The one of the artificial muscles subserves as nonlinear 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 in this appropriate half of actuator arm path and its movement and position is controlled by air pressure control. In the other half of actuator arm path the operation of actuator is the same, but the function of the muscles is replaced.

Contraction of the pneumatic artificial muscles is operated by two-position solenoid valves. The compressed air is supplied into artificial muscle trough 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 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 actuator is uniform movement of the actuator arm and accurate arm position control according to input desired variable. Some variables in system will be of discrete or impulse character.

3 STRUCTURE OF ACTUATOR ARM POSITION CONTROL

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

- 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 pneumatic artificial muscle.
- After filling of both muscles by air to maximal pressure the actuator arm will be at the reference point (zero point). At this point the stiffness will be maximum and bilateral symmetric. 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.
- One of the artificial muscles (passive) will be always filled to maximal pressure and will subserve as non-linear pneumatic spring toward to emptied and controlled (active) artificial muscle.
- The resultant stiffness of the actuator won't be constant. It will be different at different actuator arm positions and it will be higher in the stress direction of the passive artificial muscle. That is equal as by present solution of control, but its values will be maximal for every position and they will be self-aligning without necessity of using of special stiffness control loop.
- The control variables have to be in the form of discrete impulse signals on the controller output for the input to coils of solenoid valves. Accordingly the controller has to include the pulse shaping circuit for changing of continuous signal to the pulse width modulated signal and also logic decoder of outputs for solenoids.
- For the achievement of optimal dynamic characteristics, invariance and robustness the controller can also include slave velocity control loop, compensating filters and so on.

Following the previous principles of control the structural diagram of control of the actuator with pneumatic artificial muscles in antagonistic connection was designed (Fig. 2). Information about actual position of the actuator arm (φ) from the position sensing unit (K_φ) is compared with the desired variable of arm position (φ_d). The control deviation of the arm position (e_φ) is an input to the position controller (R_φ). P or PI controller can be used for position control. The controller can also include slave velocity control loop. The velocity (ω) can be derived from position. The signal shaper changes the output signal of the position controller (u) to the pulse width modulated signal (*PWM*). According to signal polarity from the output of position controller the requirement for actuator arm turning to the right or left is generated ($R/\overline{L}$). 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.

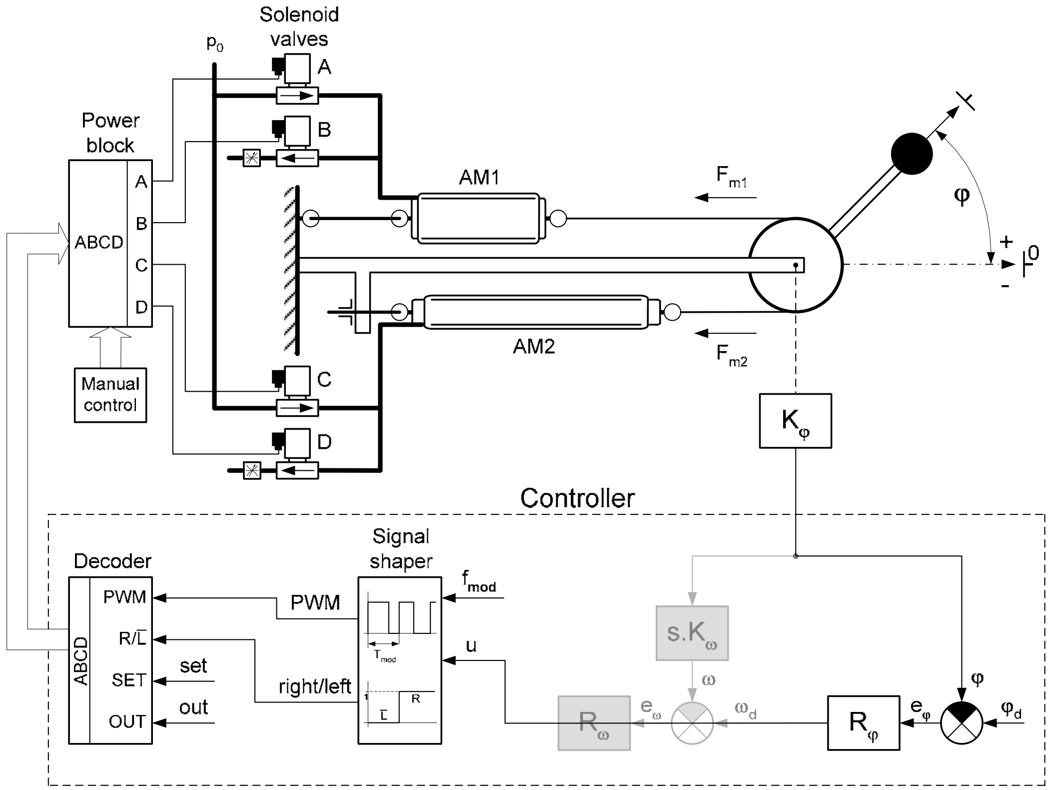

Fig. 2 Structural diagram of control of the actuator with pneumatic artificial muscles in antagonistic connection

4 BLOCK DIAGRAM OF CONTROL

On the basis presented above the block diagram of arm position control of the actuator with pneumatic artificial muscles in antagonistic connection was designed (Fig. 3):

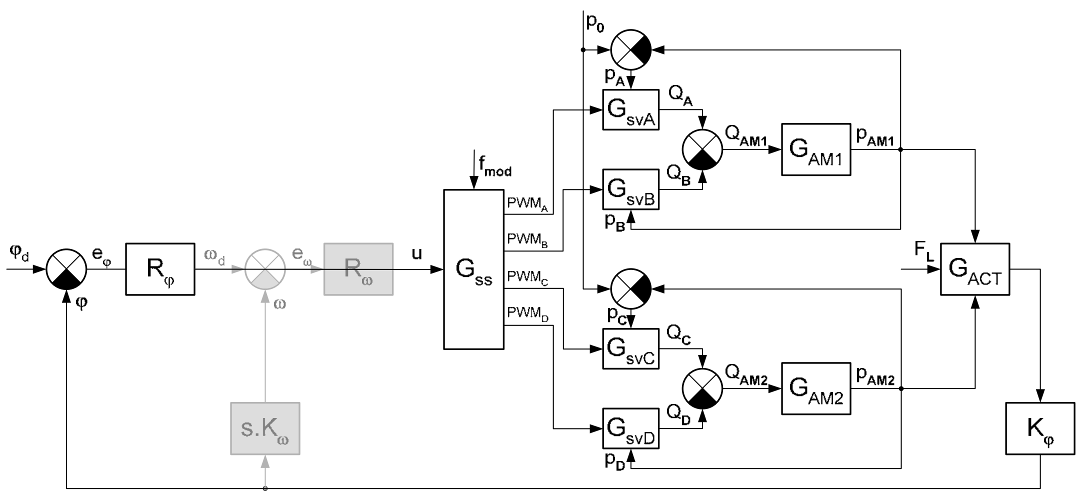

Fig. 3 Block diagram of position control of the actuator arm

The variables and blocks in block diagram on Fig. 3:

φ_d – desired variable of the actuator arm position,

φ – actuator arm position,

e_φ – control deviation of the desired and actual value of the actuator arm position,

R_φ – transfer function of the position controller,

ω_d – desired variable of the actuator arm velocity,

ω – actuator arm velocity,

e_ω – control deviation of the desired and actual value of the actuator arm velocity,

R_ω – transfer function of the velocity controller,

u – manipulated variable,

s – Laplace operator,

K_φ – transfer function of the position sensing unit,

K_ω – 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 actuator with pneumatic artificial muscles in antagonistic connection. 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.

Configuration of such actuator together with simple control system enables construction of relatively simple position bioservosystem with adequate costs and requirements for control system. 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 actuator with pneumatic artificial muscles in antagonistic connection.

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