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Research of Adaptive Force Control Loop of Electropneumatic Acting System

V. A. Geleževičius, A. Grigaitis
Department of Control Technology, Kaunas University of Technology,
Studentų str. 48, LT-51367 Kaunas, Lithuania, phone: +370 37 451610, e-mail: vilius.gelezevicius@ktu.lt

Introduction

Modeling results of non-linear electro-pneumatic acting system, consisting of proportional directional control valve and symmetric rodless pneumatic cylinder presented in the paper [1], demonstrate remarkable dependence force generation process of pneumatic cylinder on piston initial position and pressure values in cylinder working chambers. These features of pneumatic-mechanical power conversion process do not manifest they self a lot in the case when control mode “from back to back” is used, but has significant influence on control quality when proportional control principle by using proportional directional control valves and feedback technology is applied.

On purpose to minimise the influence of nonlinearities of pneumatic cylinder and directional control valve on behaviour of force electropneumatic proportional servo drive the model reference based adaptive control method of force regulation is proposed and investigated in this paper. The modelling results of proposed and investigated adaptive force control system of electropneumatic actuator are presented in the paper.

Development of structure of adaptive force control system of electropneumatic actuator

As it is seen of electrically controlled pneumatic-mechanical power conversion process force generation stage model presented in Fig. 1, all nonlinearities concerned with volume values of cylinder working chambers and initial pressures change, with nonlinearity of air flow supplying trough directional control valve ways are concentrated in the force generation stage. On purpose to eliminate influence of these nonlinearities on electropneumatic acting system state coordinates (force, velocity and position) control quality the force control process should be corrected in the corresponding way. It leads to the control strategy based on hierarchical control principle with adaptive force control subsystem application use. Because the nonlinear process parameters - volume and pressures of working chambers of pneumatic cylinder are rapidly changing, the reference model based signal adaptive control technology [2] for pneumatic cylinder developed force regulation is proposed. This needs cylinder force feedback loop application.

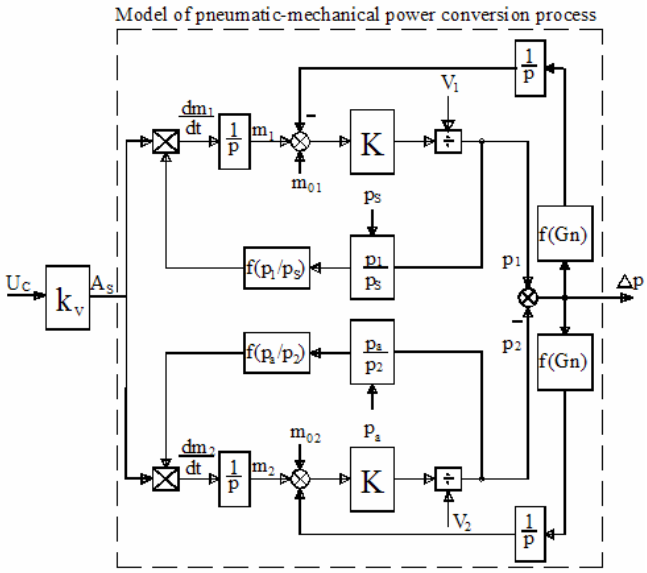

Fig. 1. The structural model of force generation stage of the electropneumatic acting system

On the base of equation expressing cylinder force dependence on the pressures of working chambers -

$$F_C(t) = [p_1(t) - p_2(t)]S, \qquad (1)$$

where $p_{1,2}$ – pressures in the cylinder champers, *Pa;* *S*- piston area, m^2, the differential pressure Δp feed back control is suggested to use.

Proposed force of pneumatic cylinder control technology can be implemented by applying commonly known force feed-back control contour in supplement with additional reference model based signal adaptive contour, generating additional control signal to main controller on purpose to compensate an influence of control system parameters change on process control quality. The functional diagram of adaptive force control system of pneumatic cylinder is presented in Fig. 2.

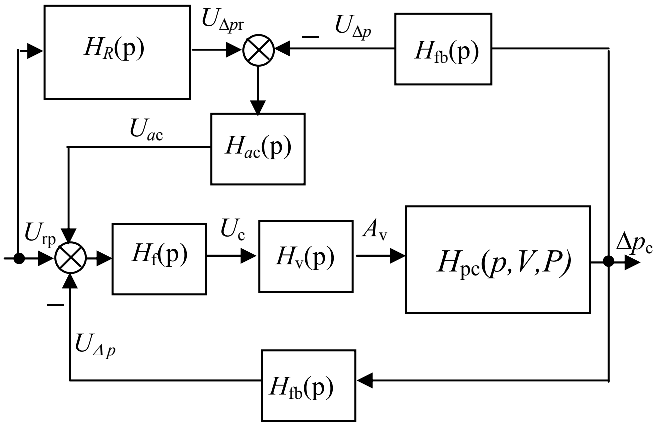

Fig. 2. Functional diagram of reference model based signal adaptive force control system of pneumatic cylinder

There in the diagram the pneumatic cylinder is presented by nonlinear transfer function $H_{pc}(p,V,P)$. The force controller $H_f(p)$, proportional directional control valve $H_v(p)$ and feed back sensor $H_{fb}(p)$ with pneumatic cylinder all together form the main force control contour. Supposing the parameters of pneumatic cylinder being constant (pneumatic cylinder is stopped) the force controller is to be adjusted under the quantitative optimum condition expressed by transfer function of open loop of force regulation contour in the form as follows [3]:

$$H_{op}(p) = H_f(p)H_v(p)H_{pc}(p,V,P)H_{fb}(p) = \frac{1}{2T_\mu p(T_\mu p+1)}, \quad (2)$$

where T_μ - freely chosen small time constant defining the desired rapidity of force regulation process.

Supposing the quality of adjusted in such way force control contour as desirable for the whole electropneumatic acting system, the transfer function of reference model for adaptive force control contour can be defined as

$$H_R(p) = \frac{U_{\Delta pr}(p)}{U_{rp}(p)} = \frac{1}{2T_\mu^2 p^2 + 2T_\mu p + 1}, \quad (3)$$

where time constant T_μ approximately equal to $T_v = 0{,}05s$.

Transfer function of adaptive controller $H_{ac}(p)$ is to be defined on the whole force control process stability condition using conventional design methods.

Design and investigation of main force controller of electropneumatic force control system

For practical investigation needs the electropneumatic force control system consisting of rodless pneumatic cylinder with *25 mm* diameter piston and *300 mm* stroke and proportional directional control valve *MPYE-5-1/8* has been chosen. For transfer function *Hpc(p,V,P)* identification the dynamical force behavior of stopped pneumatic cylinder, provoked by directional control valve orifice area A_v step mode change has been modeled. The modeling results of the case when cylinder piston is posed in the middle stroke position and initial pressures are equal to *1,5 bars* are presented in Fig. 3a.

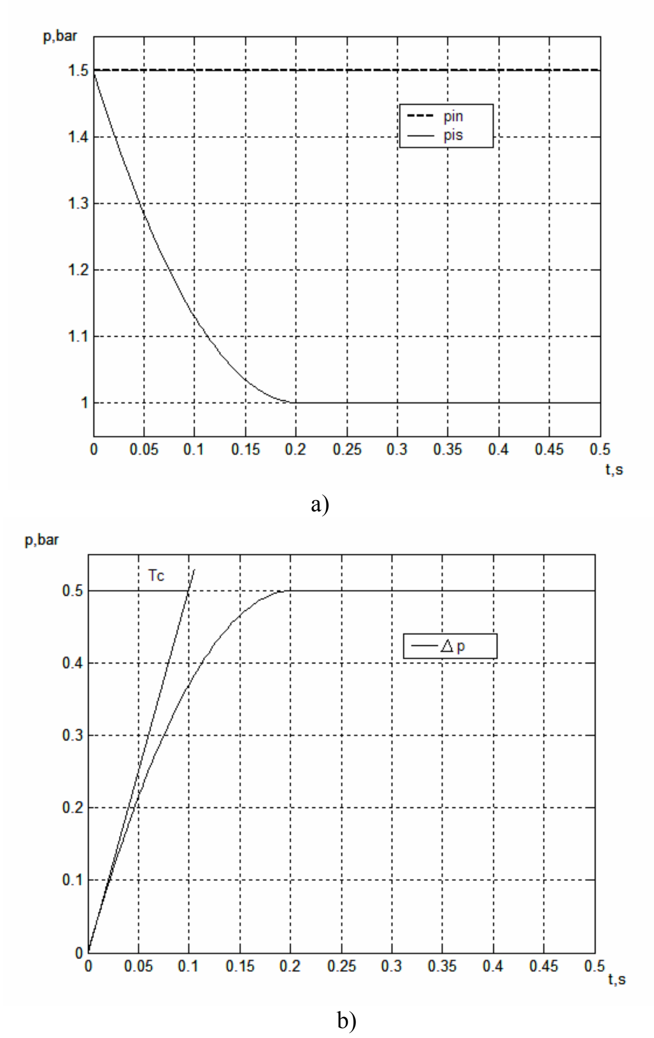

Fig. 3. Pressure in cylinder chambers response curves (a) and differential pressure response curve (b) provoked by valve orifice area step mode change

The response curves indicate that stopped cylinder may be interpreted as the first degree delay circuit with typical transfer function:

$$H_{pc}^*(p) = \frac{\Delta p}{\Delta A} = \frac{k_c^*}{T_c\, p+1}, \quad (4)$$

where $k_c^* = \frac{\Delta p}{A_v}$, A_v – orifice area of valve, m^2; T_c – time constant defined from diagram presented in Fig. 3b.

According to [4] the transfer function of proportional directional control valve also can be expressed in the form of the first degree delay circuit:

$$H_v(p) = \frac{\Delta A_v}{\Delta U_c} = \frac{k_v}{T_v p+1} \quad (5)$$

with time constant T_v approximately equal to *0,05s*.

Supposing the T_μ being equal to T_v and $H_{fb}(p) = k_p$, on the base of (3) the transfer function of main force controller is defined as

$$H_f(p) = \frac{T_c^* p + 1}{2k_v k_c^* k_p T_v p}. \qquad (6)$$

Initial pressure in working chambers and initial position of stopped piston of cylinder change influences on dynamical quality of closed-loop force control system. This influence has been investigated by modeling force regulation process under several initial conditions. The modeling results are presented in Fig. 4 and Fig. 5.

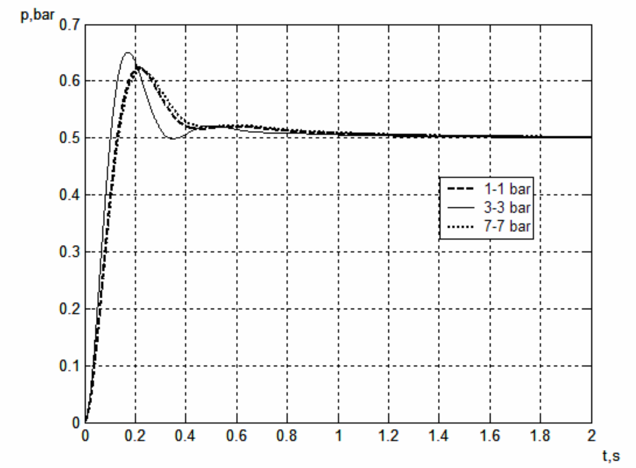

Fig. 4. Influence of initial pressure in the working chambers of cylinder on the dynamical force of cylinder control quality

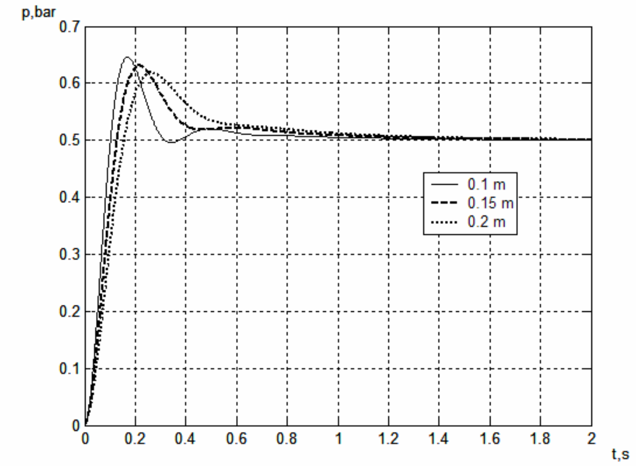

Fig. 5. Influence of initial piston position on the control of force developed by cylinder control quality

The response curves in Fig. 4 are obtained by varying initial pressure in the cylinder working chambers, the piston of cylinder being sustained in the middle stroke position.

The response curves presented if Fig. 5 demonstrate influence of piston position on force control quality the initial pressure in the working chambers being invariable and equal to *3 bars*

These modeling results confirm substantial dependence of dynamical quality of pneumatic cylinder force control process on the initial conditions defined by initial pressure in working chambers and position of piston of the cylinder change. This influence is to be minimized by applying the additional reference model based signal adaptive control contour as it is shown in Fig. 2.

Modeling results of reference model based signal adaptive force control system of pneumatic cylinder

The reference model based signal adaptive electropneumatic force control system model is presented in Fig. 6.

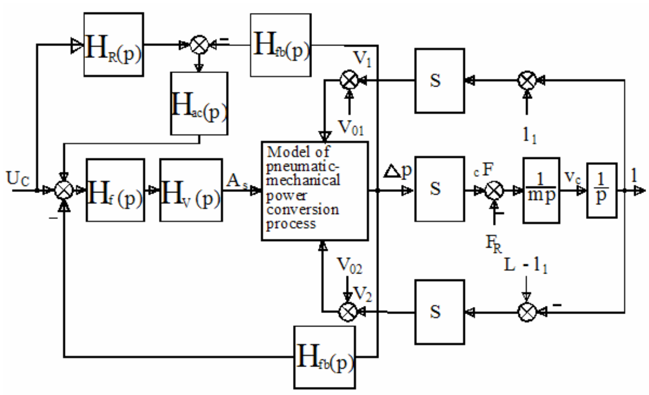

Fig. 6. The structural model of adaptive force control system of pneumatic cylinder

There in this model the pneumatic-mechanical power conversion stage of force generation process is presented in the form of bulky block having internal structure coincident with structure presented in Fig. 1. Reference model with transfer function $H_R(p)$ defined by (3) applies dynamical reference signal corresponding to quantitative optimum condition to the input of adaptive controller $H_{ac}(p)$, correcting dynamical behavior of the whole control system.

Using this model the behavior of adaptive force control system of pneumatic cylinder has been investigated in the static (piston of cylinder is fixed in certain position) and in the dynamic (piston of the cylinder moves under the action of the generated force) regimes. The model has been created using the means of *MATLAB Simulink* software.

The investigation in the static regime has been carried out when piston of the *0.3 m* length cylinder was fixed in different stroke positions equal to *0.1 m*, *0.15 m* and *0.2 m*, and initial absolute pressure of working chambers was equal to *2, 3* and *7 bars*. Response curves reflecting the dynamical behavior of adaptive force control system are presented in Fig. 7 and demonstrate good conjunction of force control process dynamical quality with dynamical quality defined by reference model in all the cases.

The dynamic regime investigations have been carried out the piston of pneumatic cylinder being released and moving under the action of the force developed by cylinder up to the end chock of the cylinder. The initial conditions – the initial position of cylinder piston and initial pressures in working chambers were changed in the same way as in the static investigation case. The modeling results are presented in Fig. 8. Comparison of dynamical regime investigation response curves with those of static regime curves presented in Fig. 7 allows concluding about good functioning of adaptive force control system in dynamical regime as well.

High frequency intensively suppressed oscillations provoked by impact of the piston to the chock on the end of cylinder are clearly seen in the dynamical regime response curves.

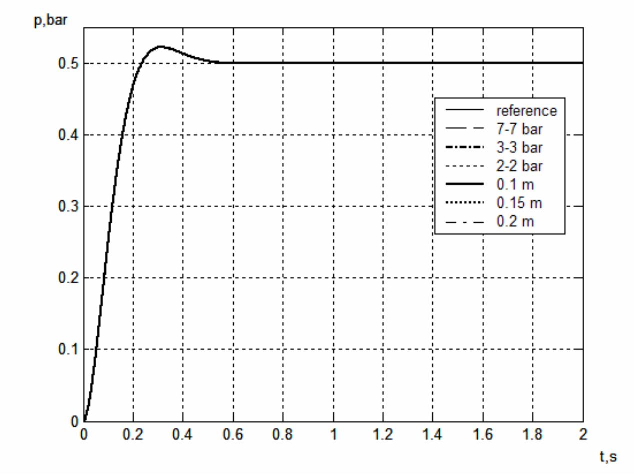

Fig. 7. Response curves of reference model and of adaptive force control system in static regime under several initial conditions

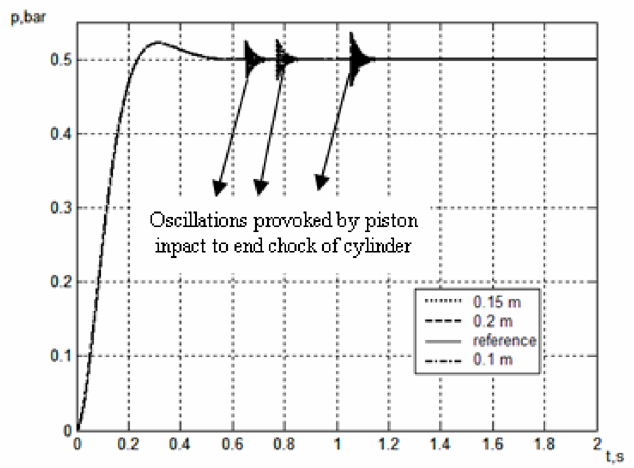

Fig. 8. Response curves of adaptive force control system in dynamic regime under several initial conditions

The place and the magnitude of these oscillations are directly depending on initial position of cylinder piston. The shorter run of cylinder piston, the faster is impact and the smaller is magnitude of generated shock oscillations.

Conclusions

1. The control system of pneumatic rodless cylinder developed force with model reference based signal adaptive controller has been presented and discussed in this article.
2. Investigations of dynamical behaviour of adaptive force regulation system has been carried out in static (cylinder piston being fixed) and in dynamic regimes (cylinder piston being released) with help of MATLAB *Simulink* software means.
3. Modeling results show excellent efficiency of signal adaptive control contour application to pneumatic cylinder force controller. Reference model based adaptive pneumatic cylinder force control system becomes invariant to initial conditions defined by initial piston position and initial pressure in working chambers of pneumatic cylinder.

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Reference model based signal adaptive force regulation contour of electropneumatic acting system is presented and investigated. It is shown that nonlinearity of pneumatic-mechanical power conversion process being concentrated in the force generation stage can be well compensated by using additional reference model based adaptive force regulation contour. The dynamical behaviour of adaptive pneumatic cylinder force regulation process has been investigated by using *MATLAB Simulink* software means. The modelling results are presented. Ill. 8, bibl. 4. (in English; summaries in English, Russian and Lithuanian).

В. А. Гяляжявичус, А. Григайтис. Исследование контура адаптивного регулирования электропневматической исполнительной системы // Электроника и электротехника. – Каунас: Технология, 2007. – № 7(79). – С. 7–10.

Представлена и исследована система электропневматической исполнительной системы с адаптивным контуром регулирования силы. Показано, что нелинейности пневмомеханического преобразования энергии сконцентрированы на тракте генерации силы, поэтому их влияние может быть компенсировано с применением контура сигнальной адаптации с эталонной моделью. Динамические свойства адаптивного контура управления силы пневматического цилиндра исследованы при помощи *MATLAB Simulink.* Представлены результаты моделирования. Ил. 8, библ. 4 (на английском языке; рефераты на английском, русском и литовском яз.).

V. A. Geleževičius, A. Grigaitis. Elektropneumatinės vykdymo sistemos adaptyvaus jėgos reguliavimo kontūro tyrimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2007. – Nr. 7(79). – P. 7–10.

Pateiktas ir išnagrinėtas etaloniniu modeliu grįstas adaptyvus elektropneumatinės vykdymo sistemos jėgos reguliavimo kontūras. Parodyta, kad pneumomechaninio energijos keitimo netiesiškumai yra sukoncentruoti jėgos generavimo trakte, todėl jų įtaką galima puikiai kompensuoti panaudojant papildomą signalinės adaptacijos kontūrą. Adaptyvios pneumatinio cilindro jėgos valdymo sistemos dinaminės savybės ištirtos modeliuojant *MATLAB Simulink* aplinkoje. Pateikti modeliavimo rezultatai. Il. 8, bibl. 4. (anglų kalba; santraukos anglų, rusų ir lietuvių k.).