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IMPROVEMENT OF THE WORK OF THE PNEUMATIC MACHINE FOR BENDING BY USING THE DIGITAL SLIDING MODE

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Abstract. *The paper deals with the problem of ensuring synchonous movement of two pneumatic cylinders in machines for bending. The control system for synchronizing was designed by applying the theory of the control system with changeable structure. The control algorithm is based on the digital sliding mode. It is assumed that it is possible to measure the coordinates of state (position and velocity) directly on the cylinder. It is shown that such a system enables quick synchronization of cylinders under varying initial conditions. The applied algorithm is compared with conventional control algorithms. Computer simulation illustrates the quality of the discussed system.*

Key words: *processing by deforming, bending, pneumatic actuator, system with valiable structure, digital sliding mode.*

1. INTRODUCTION

Processing by bending, which belongs in the field of metal processing by plastic deformation, is widespread as a branch of technology in various types of industry .

In order to process a material by bending, it must be brought into the state of plastic flow, which means that it should be loaded over the limit of elasticity. The required work and force (load) by which a tool deforms the material, is realized by machines for deforming press. According to the medium through which the force is generated, machines for deforming can be divided into:

- Mechanical,
- Electrical,
- Hydraulic,
- Pneumatic, etc.

This paper gives an improved solution for the work of the pneumatic machine for bending, where the cylinders are synchronized by the digital mode. The use of this control

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algorithmcenables quick synchronization of the work under verying initioal conditions, which are a consequence of varying external influences.

2. MACHINE FOR BENDING

To put it simply, the machine itself consists of two pneumatic cylinders, whose piston rods are connected by a lever mechanism to the ends of the bending tool. The lever mechanism is used to obtain higher deforming forces. This machine can be used for processing by bending of various profiles "U", "V", etc.

Each of the cylinders is also connected to a proportional valve 5/3 with electromagnetic activation, which serves as the supply distributor, and which can be used to direct the flow of air under pressure, i.e. the velosity of the pistons with the piston rods, i.e. the velocity of lowering the bending tool. The velocity of lowering the tool primarily depends on the type of material to be processed, i.e. on the mode of processing as stated in the technological procedure.

The supply distributors are controled by computers, which contain the data from the technological procedure. To apply the algorithm of digital control with the sliding mode, it is necessary to have information on the position and velocity of the pistons, i.e. tools. The position of tools is obtained by direct measurement by special path givers, whereas velocities can also be obtained by direct measurement, or indirectly, by differentiating position by time. Figure 1 represents a simplified scheme of the executive and control parts of the machine, without the lever mechanism, fir simplicity' sake.

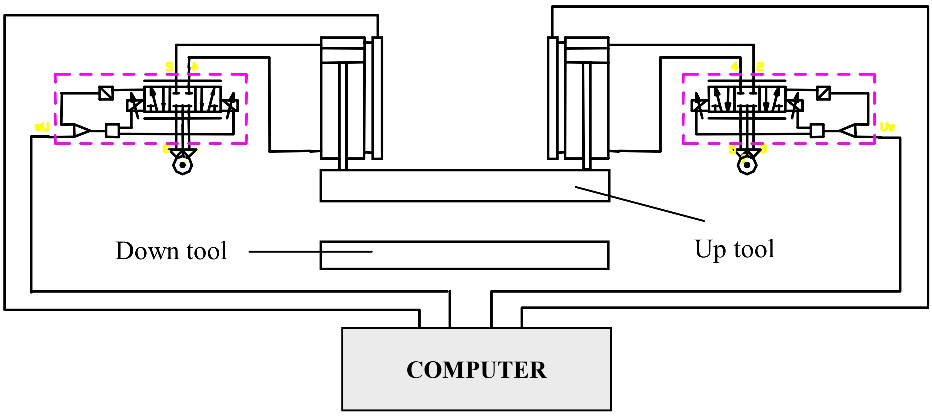


Fig. 1. Scheme of executive and control parts of the machine

The computer checks the positions of the left and right cylinders rods; on the basis of the difference, the synchronizing signal is generated in a special module for synchronizing. This signal is used to correct the constant signal which regulates the flow of air under pressure in the cylinders, and which depends on the technological procedure. Hthis new, corrected signal is used to control the supply distributors; as a consequence, the rods are brought into the same position within a very short time. Figure 2 shows the simplified way of synchronizing.

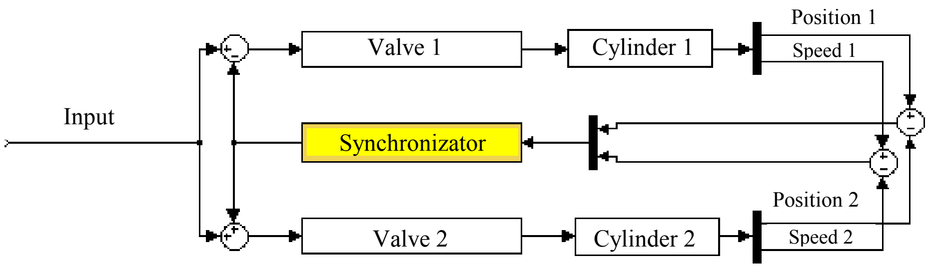


Fig. 2. Simplified representation of synchronizing two pneumatic cylinders

This synchronization is very important; otherwise, the upper tool might bend, which would result in bad processing, i.e. defective manufactured pieces. These are not completely processed, i.e. at one end we do not obtain the desired shape of bending.

2. Mathematical model of the system

In this paper, control objects are double acting pneumatic cylinders, with an electromagnet-activated valve (proportional 5/3), position indicator, and pressure sensor. Schematic representation of this system [6], together with all required values, is given in Figure 3.

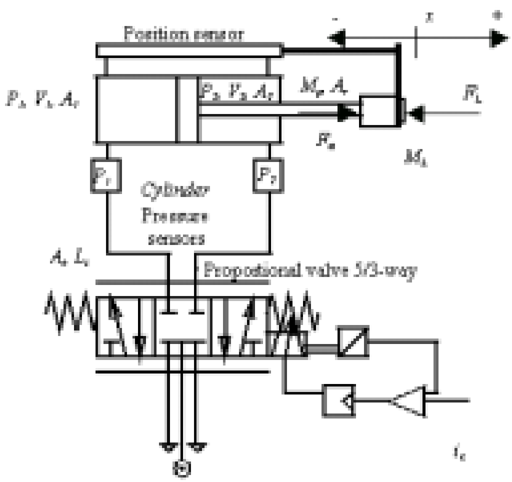
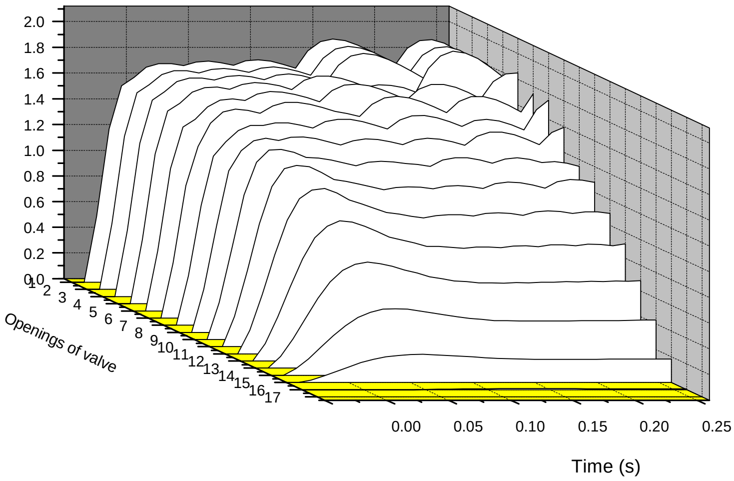


Fig. 3. Schematic representation of the pneumatic cylinder-valve system

The response of the piston rod speeds of the mathematical model, while using feeding pressure 2 bars, and at different openings of the proportional valve for feeding 5/3, is represented in Figure 4.



Valve	x_s(m)
1	0.003
2	0.0029
3	0.0027
4	0.0025
5	0.0023
6	0.0021
7	0.0019
8	0.0017
9	0.0015
10	0.0013
11	0.0011
12	0.0009
13	0.0007
14	0.0005
15	0.0003
16	0.0001
17	0.00008

Fig. 4. The response of the piston rod speeds

Since synchronization ends at very small openings of the valve of the distributor for feeding, it was here that identification of the linear model was performed, i.e. when the valve's opening is x_s=0.0001m. In this case, we have a transfer function:

$$\frac{\dot{x}_k}{u}(s) = \frac{66}{1+0.071s} \quad \Rightarrow \quad \frac{x_k}{u}(s) = \frac{66}{s(1+0.071s)} \tag{1}$$

where $\dot{x}_k$ the speed of the cylinder's piston, x_k cylinder's piston position and u=x_s is the valve's opening;
i.e. the model in the state space form is given by the relation (2),

$$\dot{\mathbf{x}} = \mathbf{A}\mathbf{x} + \mathbf{b}\mathbf{u}$$
$$\mathbf{A} = \begin{bmatrix} 0 & 1 \\ 0 & -14.0845 \end{bmatrix}, \quad \mathbf{b} = \begin{bmatrix} 0 \\ 929.577 \end{bmatrix}, \tag{2}$$

where $\mathbf{x} = [\dot{x}_k \quad x_k]^{\mathrm{T}}$.

3. Algorithm of Digital Control with Sliding Mode

The algorithm of control, whose application to the problem of synchronizing pneumatic actuators is examined in this paper, belongs to the group of digital algorithms of control of variable structure. The goal of synthesis of control is to achieve movement of the system in the space of state on a pre-given hyper-surface, in systems of the higher order, i.e. on a line (most frequently a straight line), in systems of the second order. To do so, what must be ensured is the transfer of the system's state from any initial state to the given hyper-surface and its subsequent movement on it in the sliding regime. This means that the system's phase trajectories all go into the given hyper-surface. Since it is selected so that it passes through the outcome of the space of state, which represents the state of equilibrium, asymptotic stability of the system is also ensured. In this way, the system is brought into equilibrium according to a pre-given trajectory, which may also have attributes of optimality. To summarize, the movement of these system has three phases: (I) the phase of reaching the hyper-surface; (II) the phase of the sliding regime; (III) the phase of steady state.

If the sliding hyper-surface is marked as s(**x**), the conditions are met by satisfying the inequality

$$s(\mathbf{x})\dot{s}(\mathbf{x}) < 0 \tag{3}$$

This condition can be satisfied by applying various algorithms of control. However, they must contain a relay component of type, which may give rise to parasitic movements (chattering) in the area of the hyper-surface s(**x**)=0 even in the steady state. Such movements are especially intrusive in electromechanical systems

$$U_0 \operatorname{sgn}\{s(\mathbf{x})\}, U_0 > 0 \tag{4}$$

The algorithm applied in this paper eliminates or minimizes the problem of vibration to a tolerable level. The control is formed so that it has two components: a relay component, which ensures safe and quick transfer of the system's state near the sliding hyper-surface without intersecting it, and a linear component, which brings the system's state into s(**x**)=0 in the following step (during one discretization period).

In shortest, the applied algorithm , which is described in [3] in detailed, can be represented in the following way.

For a given controllable and observable dynamic system

$$\dot{\mathbf{x}} = \mathbf{A}\mathbf{x} + \mathbf{b}u; \quad \mathbf{x} \in R^n, u \in R^1, \mathbf{A}_{nxn}, \mathbf{b}_{nx1} \tag{5}$$

With slowly changing parameters within limits known in advance, whose digital equivalent

$$\delta\mathbf{x}(kT) = \mathbf{A}_\delta(T)\mathbf{x}(kT) + \mathbf{b}_\delta(T)u(kT) \tag{6}$$

is obtained by applying relation

$$\mathbf{A}_\delta(T) = \frac{e^{\mathbf{A}T} - \mathbf{I}_n}{T}, \quad \mathbf{b}_\delta(T) = \frac{1}{T}\int_0^T e^{\mathbf{A}\tau}\mathbf{b}d\tau, \tag{7}$$

The sliding regime is organized on hyper-surface s(**x**), whose equation in the state space is

$$s(\mathbf{x}(k)) = s(k) = \mathbf{c}_\delta^{\mathrm{T}}(T)\mathbf{x}(k) = 0; \mathbf{c}_\delta^T(T)\mathbf{b}_\delta(T) = 1 \tag{8}$$

By substituting (6) in (8) and solving the obtained equation according to *u(k)*, we obtain,

$$u(k) = -\mathbf{c}_\delta^{\mathrm{T}}(T)\mathbf{A}_\delta(T)\varepsilon(k) - \Phi(s(k), \mathbf{X}(k)) . \tag{9}$$

Such control signal corrects the constant signal of the flow of air under pressure on proportional valves.

The pneumatic system to be considered in this section consists of two double acting pneumatic cylinders whose work should be synchronized, since they have different initial positions (Figure 5).

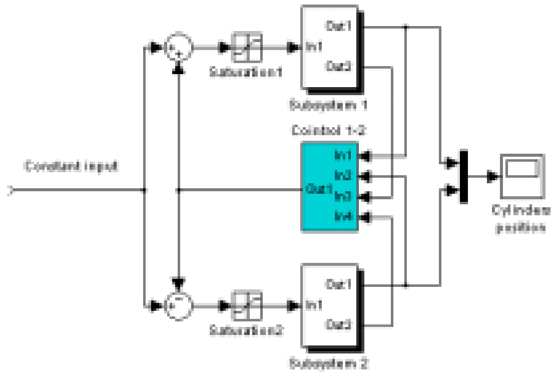


Fig. 5. Schematic representation of synchronization of two pneumatic cylinders.

The system's model, given in state space form by equation (2), is discretized by means of transformation (7), with discretization period 0.1s. The sliding hyper-surface coefficient is calculated by means of equation (28), for $\alpha = 20s^{-1}$. Parameters q and σ are taken to be 0 and 10, respectively. Vector $\mathbf{c}_\delta(T) = [0.016333521\ \ 0.00100545]$ and $\mathbf{c}_\delta(T)\mathbf{A}_\delta(T) = [0\ \ 0.0021764]$. Different initial positions are reflected in the fact that the piston rod of the first cylinder is already somewhat drawn out, whereas the piston rod of the other cylinder is completely pulled in.

The problem of synchronization is to bring, within a short period of time, the positions of both cylinders (x_1 and x_2) into equal positions, with no differences in further work. In order to successfully solve this problem of synchronization in the manner described in section 3, the algorithm of digital control, given in equation (9), is used, which ensures that errors in positions and speeds of the piston rods are eradicated within a short period of time.

To confirm that the algorithm of control, which enables quick synchronization, was adequately selected, Figure 6 shows simulated results of the positions of standard pneumatic cylinders, maximal range 0.25m. As has been mentioned, initial positions of the cylinders differ; in this case, the piston rod of the first cylinder C_1 is at initial position x_{10}=0.05m, whereas the piston rod of the other cylinder C_2 is completely pulled in, i.e. x_{20}=0m. Figure 6a shows the work of the system when synchronization is performed, while Figure 6b shows the result of the position error, where can be seen that position error becomes zero within a short period of time.

Parametars of PI regulator are $K_P = 0.003$ and $K_I = 0.0001$.

The occurrence of chattering is the consequence of the application of the algorithm of control to the real model.

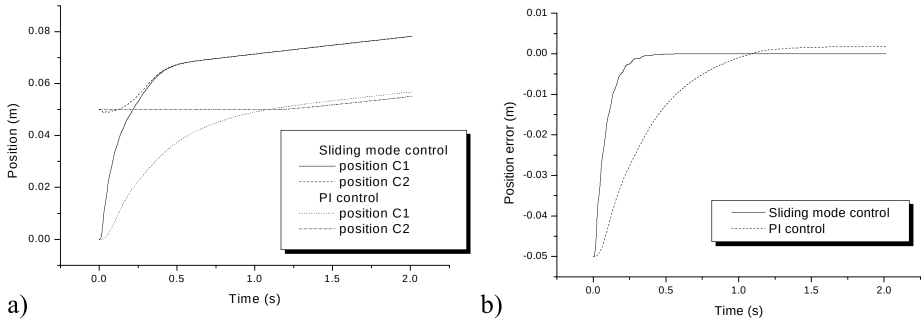


Fig. 6. Simulated results of the positions of standard pneumatic cylinders: algorithm of digital control with sliding mode and PI regulator, and b) position error.

4. CONCLUSION

The paper discusses the problem of synchronizing the work of two cylinders on the pneumatic machine for bending; it also outlines the algorithm of digital control which solves this problem. The control algorithm serves its purpose, since it enables synchronizing the work of cylinders within a short period of time, which was shown and explained in chapter 3. This way of synchronizing pneumatic cylinders with bilateral effect used in pneumatic machines for bending, makes realization much simpler and cheaper, and yields better quality of manufactured pieces.

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POBOLJŠANJE RADA PNEUMATSKE MAŠINE ZA SAVIJANJE KORIŠĆENJEM DIGITALNOG KLIZNOG REŽIMA

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Razmatra se zadatak obezbeđenja sinhronog kretanja dva pneumatska cilindra kod mašine za savijanje. Upravljački sistem za sinhronizaciju projektovan je primenom teorije sistema upravljanja promenljive strukture. Algoritam upravljanja se bazira na digitalnom kliznom režimu. Pretpostavlja se da se na cilindrima mogu neposredno meriti koordinate stanja: pozicije i brzine. Pokazano je da takav sistem obezbeđuje brzu sinhronizaciju cilindara pri različitim početnim uslovima. Izvršeno je upoređenje primenjenog algoritma sa konvencionalnim algoritmima upravljanja. Simulacijom na računaru ilustrovan je kvalitet rada razmatranog sistema.

Ključne reči: *Obrada deformisanjem, savijanje, pneumatski aktuator, sistem promenljive strukture, digitalni klizni režimi.*