SYNCHRONIZATION SYSTEM OF THE HYDRAULIC CYLINDERS MOTION IN THE RESEARCH OF THE BRIDGE PRESTRESSING SYSTEMS

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Summary

The safety of the peoples using with the bridges which are made in the prestressing concrete technology, is dependent on the quality of the elements of the applying prestressing system. Thus the research of the bridge prestressing system, particularly static research, are conducted in the conditions which simulate the real loads affecting on the each elements. Such defined conditions of the conducting of the prestressing systems research need the building of the adequate research stand. The article presents the system conception of the hydraulic cylinders motion synchronization, which will be used in the prestressing systems research. The mathematical model was presented also with the results of the simulation researches.

Keywords: prestressing concrete, static research, synchronization of motion.

UKŁAD SYNCHRONIZACJI RUCHU SIŁOWNIKÓW HYDRAULICZNYCH
W BADANIACH MOSTOWYCH USTROJÓW SPRĘŻAJĄCYCH

Streszczenie

Bezpieczeństwo ludzi korzystających z mostów wykonanych w technologii betonów sprężonych zależy w bardzo dużym stopniu od jakości elementów zastosowanego ustroju sprężającego. Stąd badania mostowych ustrojów sprężających, a w szczególności badania statyczne są przeprowadzane w warunkach, które symulują rzeczywiste obciążenia działające na poszczególne elementy. Jednak tak zdefiniowane warunki przeprowadzania badań ustrojów sprężających wymagają budowy odpowiedniego stanowiska badawczego. Artykuł prezentuje koncepcję układu synchronizacji ruchu siłowników hydraulicznych, który to układ zostanie wykorzystany w badaniach ustrojów sprężających. Przedstawiono również model matematyczny układu wraz z wynikami badań symulacyjnych.

Słowa kluczowe: betony sprężane, badania statyczne, synchronizacja ruchu.

1. INTRODUCTION

The safety of the peoples using with the bridges which are made in the prestressing concrete technology, is dependent on the quality of the elements of the applying prestressing system. Thus the research of the bridge prestressing system, particularly static research, are conducted in the conditions which simulate the real loads affecting on the each elements. The ETAG 013 norm defines the conditions, in which the research have to be conducted. The research procedure contains following stages:

- tension of the strings is realized by the stressing devices which are used in the building of the prestressing structure. The force of tension should be increased with the constant speed of 100 MPa per minute,
- transfer of the tension force from the stressing devices to body of laboratory stand after reach the level of 80 % of the characteristic strength of the strings by the tension force,
- the tension force is kept at the level of 80 % of the characteristic strength during 1 hour,
- the increasing of tension force with the maximal speed of the strain increase of 0,002 per minute until the failure of the one or more strings[1].

Such defined conditions of the conducting of the prestressing systems research require the building of the adequate research stand. Taking into consideration that the characteristic strength of the strings applying in the prestressing bridge building amount to 279 kN, the value of the necessary force increase with the increase of the strings number in the anchoring block. The obtainment of such force value is possibility by the using of hydraulic

[1] ETAG 013 Guideline for European Technical Approval of Post-tensioning Kits for Prestressing of Structure, June 2002

cylinders system. The cylinders motion synchronization in such system is difficulty by the randomness of the hydraulic cylinders load resulting among other from slip in the jaws.

2. LABORATORY STAND FOR THE PRE- AND POST-TENSIONED RESEARCH

2.1. The building of laboratory stand

The laboratory stand to the static research consists of three following main parts: body, movable disc and four cylinders system (fig. 1).

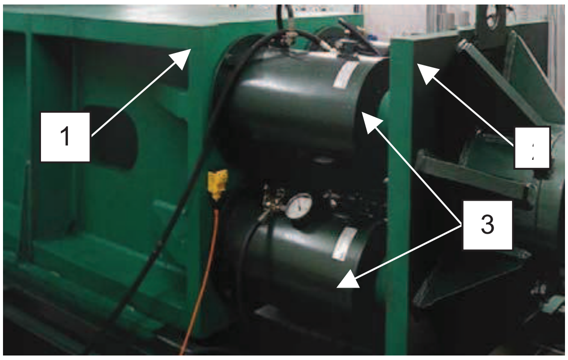

Fig. 1. View of the laboratory stand:
1-body of the stand, 2-movable disc, 3- four cylinders system

The system of four cylinders has the following tasks:

- load increase of the movable disc with the maximal speed of displacement increment of 0,002 per minute until one or more string scarifying,
- load decrease of the movable disc after 1 or more string scarifying (the rest of strings still carry the load).

2.2. The characteristics of the synchronization process

The general characteristics are following:

- maximal speed of the cylinders motion approximates 0,000641 [m/s],
- external forces P1(t),...,P4(t) (fig. 2) are randomly changeable,
- range of the value changes of external forces approximates from 0 to 2162 [kN].

The maximal speed results from the ETAG 013 requirements according to which the maximal speed of the displacements increase in the stretched strings can't be bigger than 0,002 per minute. It results from the length of the tensioned strings which amount to 6 m for described laboratory. The load of the movable disc depends from the researched anchored block (fig. 3).

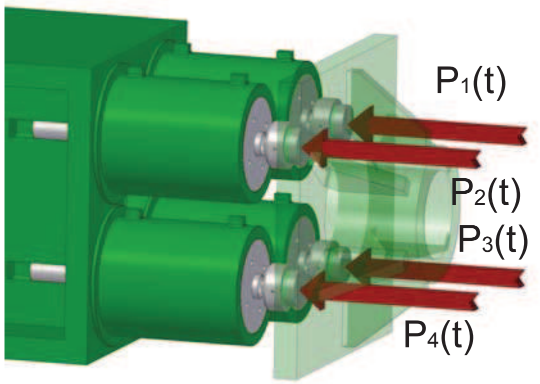

Fig. 2. Force distribution on the cylinder piston

Thus, the number of the strings can range from 1 to 32 and needed force also increases (tab. 1).

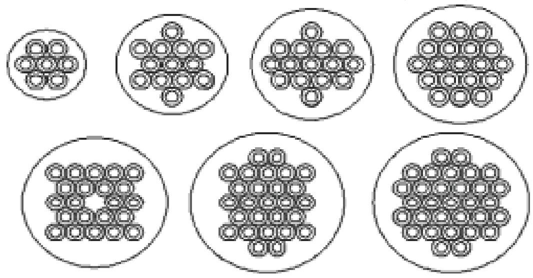

Fig. 3. Kinds of the anchored blocks

Table. 1. The needed forces values

Number of the strings	7	12	13	15	19	31
The force value[kN]	1953	3348	3627	4185	5301	8649

The values of the external forces P1(t),...,P4(t) change from the point of view of occurrence of the following phenomena:

- slides of the strings in the jaws,
- displacements of the jaw in anchored block (fig. 4),
- friction between the movable disc and body of the laboratory stand.

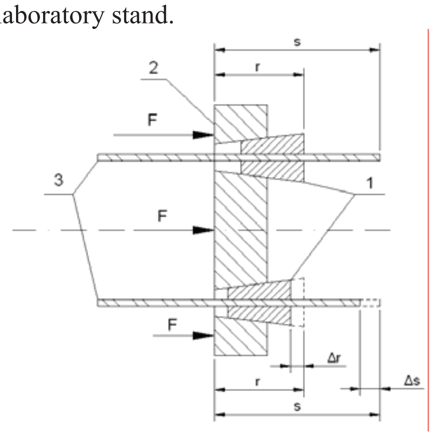

Fig. 4. Asymmetry of displacements of the jaw in the anchored block: 1-jaws, 2- anchored block, 3 – strings

2.3. Hydraulic structure of the synchronization system

The hydraulic structure of the synchronization system (fig. 6) was based of the basic hydraulic elements like throttle valves. The achievement of the required accuracy of synchronization will be realized by adequate control algorithm.

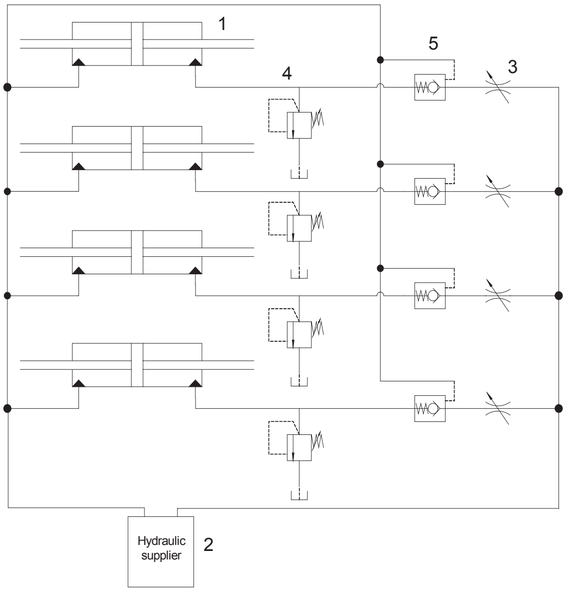

Fig. 5. Hydraulic structure of the synchronization system

Fig. 5 presents the hydraulic structure of the cylinders motion synchronization system. The system consists of the four hydraulic cylinder (1), control hydraulic supplier (2), four throttle valves (3) which are controllable by the corresponding stepping motors, four relief valves (4), four hydraulic locks (5). The presented system work in the open-loop of control. This way of control doesn't enable to eliminate the displacement cylinders differences which are caused by the compressibility of the working fluid with the high external load changes. Obviously, the hydraulic structure could be other by the application other hydraulic elements such as a flow synchronizator. The view of this system is presented in fig. 6.

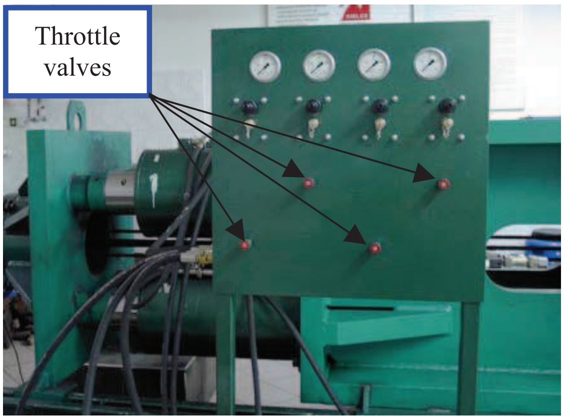

Fig. 6. The view of synchronization system

3. MATHEMATICAL MODELLING OF THE SYNCHRONIZATION SYSTEM

3.1. The basic assumptions of the system work

The main assumption, apart from the elimination of the synchronization mistakes, is the minimization of the energy losses in this system. It can be achieved by the minimization of the energy looses in the maximal valve. Thus, the following condition must be granted:

$$p_1(t) < p_{max}(t) \tag{1}$$

where: $p_1(t)$ - the pressure in the common input lines (fig. 7)

$p_{max}(t)$ - the pressure set in maximal valve

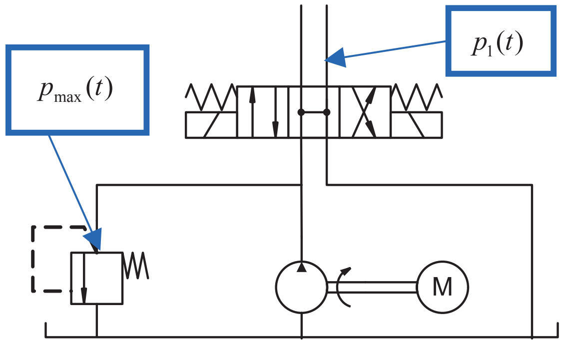

Fig. 7. Structure of the hydraulic supplier

However, the fulfilment of condition (1) leads to the multivariable structures of control system (fig. 8) and generates difficulties with the choice of leading cylinders.

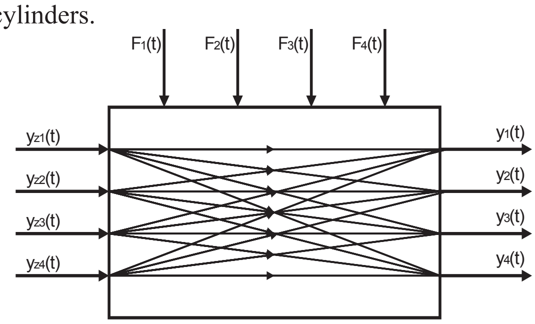

Fig. 8. Signal flow in the control system
$y_i(t)$– displacement of the piston of cylinder,
$y_{zi}(t)$ – displacement of the moving pin of throttle valve,
$F_i(t)$ – unknown external load

3.2. The basic assumptions to the mathematical modelling

The basic assumption to the building of the mathematical model:

- parameters of the elements are concentrated;
- surfaces and masses of every pistons and pin of throttle valve are identical;
- there is laminar flow in all the local elements;
- there is turbulent flow in all the linear elements;
- fluid temperature is constant;
- stream of fluid is continuous;

- connecting conduits are short and rigid (pressure losses in this conduits are negligible);
- dry friction doesn't occur in the surfaces of the carry-out elements.

3.3. The mathematical model

The calculated schema is presented in fig. 9.

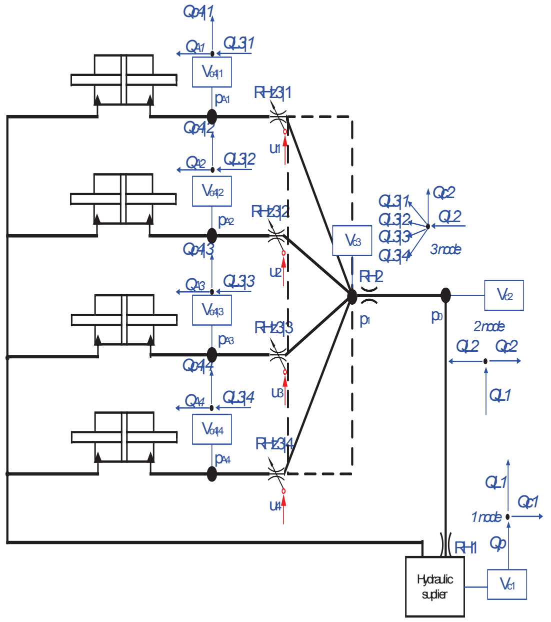

Fig. 9. The calculated schema of four hydraulic cylinder synchronization system

The basic equations are following:

$$\frac{d^2 y_i(t)}{dt^2} = \frac{1}{m_{zs}}[Ap_{Ai}(t) - F_i(t) - F_{ti}\left(\frac{dy_i(t)}{dt}\right) + \\ - k_{sc}((\mathrm{sgn}(y_i(t)+l_c)+1)(y(t)+l_c)+(\mathrm{sgn}(y_i(t))+1)y_i(t))] \quad (2)$$

$$\frac{dp_{Ai}(t)}{dt} = \frac{E_C}{V_0 + Ay_i(t)}\left[Q_{Ai}(t) - A\frac{dy_i(t)}{dt} - k_p p_{Ai}(t)\right] \quad (3)$$

$$\frac{d^2 y_{zi}(t)}{dt^2} = \frac{1}{m_z}\left(k_u u_i(t) - f_{tz}\frac{dy_{zi}(t)}{dt} - \frac{\rho}{\pi d}\cos\varepsilon Q^2_{Ai}(t) y_{zi}(t)\right) \quad (4)$$

$$\frac{dQ_{Ai}(t)}{dt} = \frac{A_{pi}}{\rho l_{pi}}[p_1(t) - p_{Ai}(t) - (0.5\lambda_l \frac{l_{1i}\rho}{2d_{1i}A_{1i}{}^2} + 0.5\lambda_l \frac{l_{Ai}\rho}{2d_{Ai}A_{Ai}{}^2} + \\ + \frac{\rho}{2C_d{}^2 f_{di}(y_{zi})^2} + \frac{\rho}{2C_d{}^2 A_{zh}{}^2})Q_{Ai}(t)^2] \quad (5)$$

$$\frac{dp_1(t)}{dt} = \frac{E}{V_1}\left(Q_p - Q_{A1}(t) - Q_{A2}(t) - Q_{A3}(t) - Q_{A4}(t) - Q_{An}(t)\right) \quad (6)$$

where:

$$F_{ti}\left(\frac{dy_i(t)}{dt}\right) = f_l\frac{dy_i(t)}{dt} - F_{tk}\,\mathrm{sgn}\left(\frac{dy_i(t)}{dt}\right) - F_{tp}\exp\left(-\frac{\frac{dy_i(t)}{dt}}{v_k}\right)\frac{dy_i(t)}{dt}\mathrm{sgn}\left(\frac{dy_i(t)}{dt}\right)$$

$$f_{di}(y_{zi}) = tg\frac{\alpha}{2}\left(y_{z0} + y_{zi}(t)\right)^2$$

$y_i(t)$ – displacement of the piston of cylinder, $p_{Ai}(t)$ – pressure in the A chamber of cylinder, $F_i(t)$ – unknown external load $F_{ti}\left(\frac{dy_{zi}(t)}{dt}\right)$- friction force $Q_{Ai}(t)$ – flow between throttle valves and A chamber of cylinder $y_{zi}(t)$ – displacement of the moving pin of throttle valve, $p_1(t)$ – the pressure in the common input branch, $u_i(t)$ – the control signal from the stepping motor, , m_{zs} – reduced mass of the cylinder, A – surface of pistons, k_{sc} – coefficient of the elasticity of cylinder, E_c – modulus of elasticity of the fluid, V_0 – initial volume of the cylinder chamber k_p – coefficient of the leaks, k_u – coefficient of the stepping motor, f_{tz} – coefficient of viscous friction in the throttle valves, ρ – density of the fluid, A_{pi} – surface of the conduits, l_{pi} – length of the conduits, m_z – reduced mass of the moving pin of throttle valve, C_d – coefficient of the flow through the throttle valve, α – the angle which depends on the construction of throttle valve, Q_p – flow from the supplier.

The schema of the signal flow is presented in fig. 10.

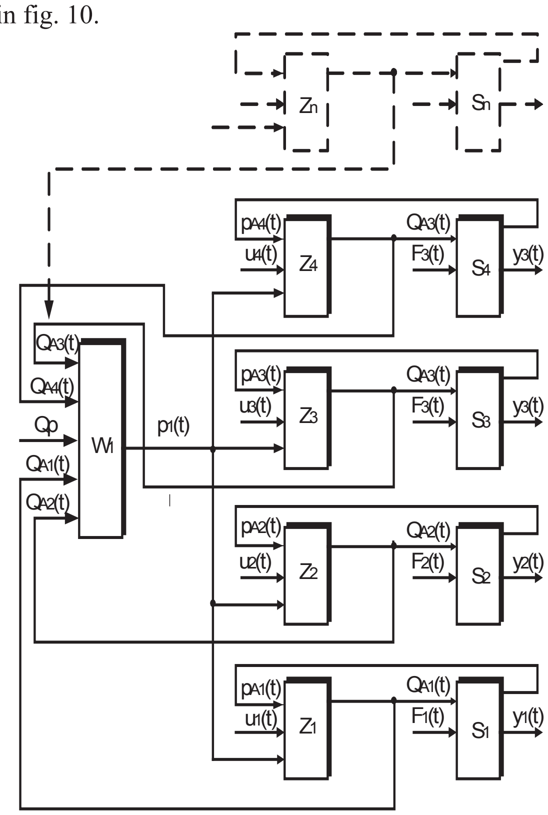

Fig. 10. The schema of the signal flow
W_1- input conduit, Z_i – throttle valves, S_i - cylinders

Presented over mathematical model of four hydraulic cylinders can describe in states space:

$$\begin{bmatrix} \dot{x}_{1n} \\ \dot{x}_{2n} \\ \dot{x}_{3n} \\ \dot{x}_{4n} \end{bmatrix} = \begin{bmatrix} A_1 & A_s & A_s & A_s \\ A_s & A_2 & A_s & A_s \\ A_s & A_s & A_3 & A_s \\ A_s & A_s & A_s & A_4 \end{bmatrix}\begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} + \begin{bmatrix} B_1 & 0 & 0 & 0 \\ 0 & B_2 & 0 & 0 \\ 0 & 0 & B_3 & 0 \\ 0 & 0 & 0 & B_4 \end{bmatrix}\begin{bmatrix} u_1 \\ u_2 \\ u_3 \\ u_4 \end{bmatrix}$$

where: A_i – state matrix for each throttle valve-cylinder systems;
B_i – control matrix for each throttle valve-cylinder systems;
A_s – feedback matrix between throttle valve-cylinder systems.

3.4. The simulation experiment

Presented mathematical model was implemented to the Matlab Simulink program. Simulation diagram for equations is shown in figure 11.

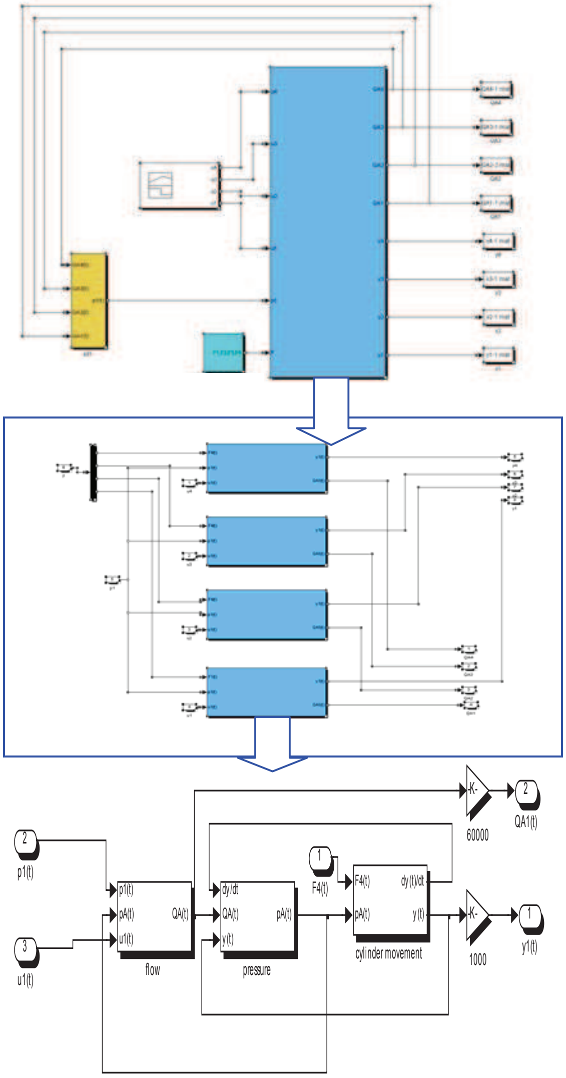

Fig. 11. Simulation diagram for synchronization system

Simulations was conducted for the parameters, which are presented in tab 2. The value of parameters was determined according to the construction conditions of the laboratory stand.

Table 2. The value of parameters

Q_z	A	E_C	k_p	m_{zs}
m^3/s	m^2	MPa	m^5/Ns	kg
$6{,}6*10^{-5}$	0,065	$1{,}4*10^3$	10^{-12}	10
V_0	f_{tz}	C_d	k_{sc}	A_{pi}
m^3	Ns/m	-	N/m	m^2
$2*10^{-5}$	300	0,6	$1*10^{10}$	$3{,}1*10^{-6}$

In the simulation model, a change of the external load acting one 1 cylinder was established in order to determination of the effect among particular throttle valve - cylinder system. The course of basic characteristics are presented in fig. 12.

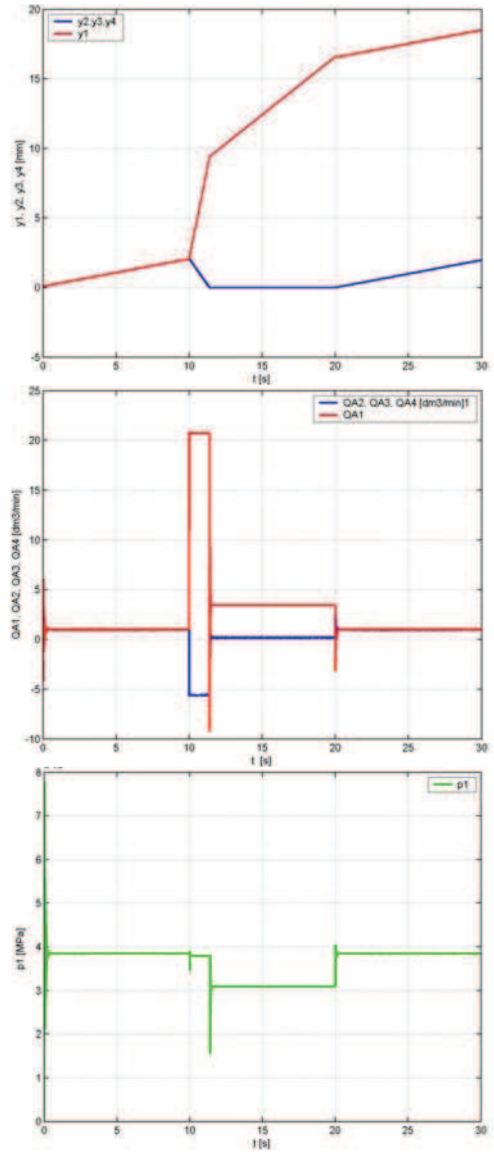

Fig. 12. Characteristics for the change of the force effecting on 1 cylinder

In the second simulation test, the change of the setting of throttle valve was established in order to definition of the interactions among particular control signal u1(t). The course of basic characteristics are presented in fig. 13.

Taking into consideration that the pressure in the input conduit is changeable, the change of external load acting on 1 cylinder have the effect on the motion of other cylinders. Hence, the application of control system based a super-ordinated cylinder, which the piston displacement is a input signal for other cylinders is only possible in the situation when the super-ordinated cylinder is the most loaded. However, the cylinder load s changeable, hence super-ordinated cylinder will have to be change.

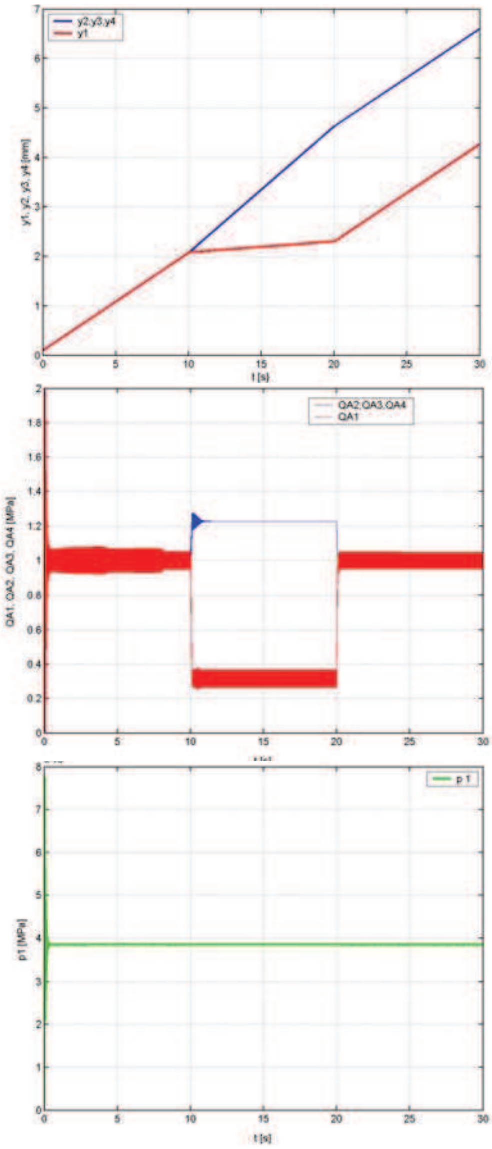

Fig. 13. Characteristics for the change of the throttling surface in 1 throttle valve

4. CONCLUSIONS

1. The research requirements resulted from adequate norms demand the using of the big forces, which are possible to get by the application of the set consisting of several cylinders.
2. The long-tasking of the research causes the large energy losses, which can be decreased by the using of the system with changeable value of the input pressure.
3. The application of such system causes the necessity of elaboration of the control system algorithm because the system with super-ordinated cylinder can be used.

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