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SYNTHESIS OF MINIMAL SCHEMES OF SYSTEMS CONTROL OF HYDRAULIC AND PNEUMATIC DRIVES

The existing schemes of command apparatus are presented. Their analysis is carried out and the shortcomings are indicated. The scheme of a fundamentally new command apparatus is given, which can significantly reduce the number of its elements. The synthesis of the pneumatic control system of the foundry machine was carried out on the basis of the design approach proposed by M. Cherkashenko, which as a result led to a reduction in the devices by 3.5 times. A graph of operations of the pneumatic control system of the molding machine is constructed. A matrix of correspondences is obtained, which determines the correspondence between the signals that cause transitions and the complete input sets acting in the transitions. Analysis of the matrix of correspondences made it possible to identify and eliminate contradictory transitions. On the basis of the elongations, a system of equations describing the scheme of the control system is synthesized. Further, minimization is performed due to factorization and decomposition of equations, and obtaining equations in their final form. A diagram is presented pneumatic control system of the molding machine, consisting of a command apparatus containing three cells, five cylinders, two vibrators, six limit switches, a time relay and other devices. The circuit simultaneously uses the functional and logical capabilities of limit switches, the possibility of implementing the functions of three variables by distributors. Thus, the use of the proposed command apparatus, in contrast to the existing schemes of command apparatus, can significantly reduce the number of distributors in the synthesis of the command apparatus itself and significantly reduce the number of elements when using the chosen approach to the design of circuits of pneumohydraulic control systems.

Keywords: mathematical model, graph of operations, minimal scheme, equations, matrix of correspondences, command apparatus.

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СИНТЕЗ МІНІМАЛЬНИХ СХЕМ СИСТЕМ УПРАВЛІННЯ ГІДРО- І ПЕВМОПРИВОДІВ

Представлені існуючі схеми командоапарату. Проводиться їх аналіз і вказуються недоліки. Наведено схему принципово нового командоапарату, який дозволяє значно скоротити кількість його елементів. Синтез пневматичної системи управління ливарним верстатом здійснювався на основі конструктивного підходу, запропонованого М. Черкашенко, що в результаті призвело до скорочення пристроїв в 3,5 рази. Побудовано граф операцій пневматичної системи управління формувальної машини. Синтезована матриця відповідностей, яка визначає відповідність між сигналами, що викликають переходи, і повними вхідними множинами, що діють в переходах. Аналіз матриці відповідностей дозволив виявити і усунути суперечливі переходи. На основі подовжень синтезується система рівнянь, що описують схему системи управління. Далі виконується мінімізація за рахунок факторизації і розкладання рівнянь, і отримання рівнянь в їх кінцевому вигляді. Представлена схема пневматичної системи управління формувальної машини, що складається з командоапарату, що містить три осередки, п'ять циліндрів, два вібратори, шість кінцевих вимикачів, реле часу та інші пристрої. Схема одночасно використовує функціональні та логічні можливості кінцевих вимикачів, можливість реалізації розподільниками функцій трьох змінних. Таким чином, застосування запропонованого командоапарату, на відміну від існуючих схем командоапаратів, дозволяє значно скоротити кількість розподільників при синтезі самого командоапарату і значно зменшити кількість елементів при використанні обраного підходу до проектування схем пневмогідравлічних систем управління.

Ключові слова: математична модель, граф операцій, мінімальна схема, рівняння, матриця відповідностей, командоапарат.

Existing command apparatuses. In Fig. 1, *a*, *b* shows the schemes of command devices designed for the implementation of the memory unit in pneumatic high-pressure control systems. In these devices, when a signal is applied S to one of the inputs on one of the outputs signal $y = 1$, and on the rest – signals $y = 0$. In addition, when the next distributor of the chain is turned on, the previous one is turned off (the first one is considered the next after the last distributor).

Command apparatus (Fig. 1, *b*). The input signals in it are fed not to the control chambers of the distributors, but to their input channels. In addition, each subsequent distributor turns off the previous one and turns on the next one and thereby prepares it to receive the input signal. The circuits (Fig. 1, *a*, *b*) are passive, require the installation of additional elements to return the distributors to their original position, but in some cases allows you to save elements.

The command apparatus (a.s. no. 1242926) (Fig. 2) increases the speed of its shutdown, but has a significant number of distributors sheme.

The command apparatus works in this way. Signals in the initial position $x_1 – x_n$ in input channels and signals $y_1 – y_n$ in the output channels are zero. During the start signal p_n through the $\vee$ the distributor 1 of the first cell is switched, the supply pressure enters the output channel ($y_1 = 1$). During the signal $x_2 = 1$ the distributor 2 of the second cell is switched, the output signal of which will cause the switch of the distributor 1 of the second cell, the output signal $y_2 = 1$. This signal through the $\vee$ turns off the allocator 1 of the first cell, as a result $y_1 = 0$.

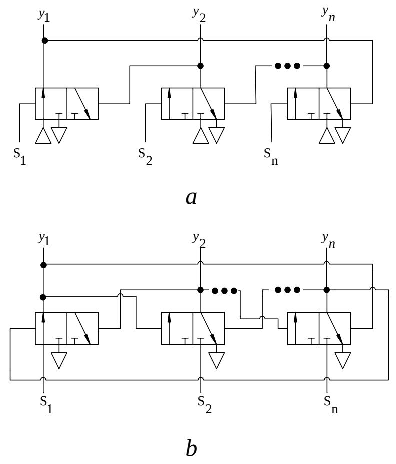

Fig. 1. Scheme of command apparatus built on switchgears

Sequential input $x_i = 1$ will cause sequential generation of output signals $y_i = 1$. During the shutdown signal p_0, regardless of the presence of an input signal $x_i = 1$, all distributors 2 are switched by connecting the control chambers of the distributors 1 to the atmosphere. At the same time, the signal p_0 through the elements $\vee$ passes into the control chambers of the distributors 1, which causes the removal of output signals ($y_i = 0$). If the valves are removed from this diagram $\vee$, connected to the emergency reset signal, we get a well-known scheme of the command apparatus with the control of the previous stroke.

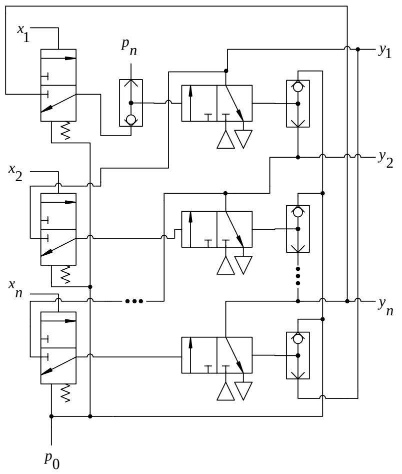

Fig. 2. Scheme of the command apparatus built on distributors and valves

In the scheme of the command apparatus (a.s. no. 1303656), shown in Fig. 3, used to memorize signals logic gates, which can reduce the number of elements, but has a large number of distributors.

The command apparatus works in this way. In the initial position, the signals at the inputs (x_1, x_2, …, x_n) and outputs (y_1, y_2, …, y_n) are equal to 0. When a signal is given ($p_n = 1$) to the input of the element $\vee$ the allocator 1 of the first cell is switched. In this case, the supply pressure is supplied to the output of the first cell ($y_1 = 1$).

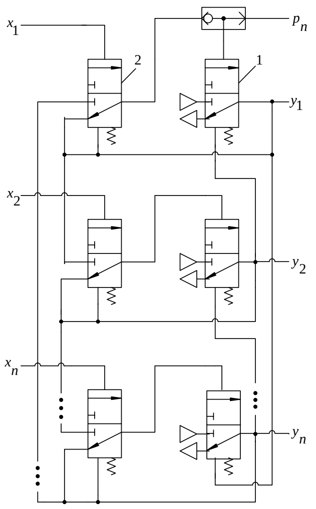

Fig. 3. Scheme of the command apparatus using distributors with one-way control

At the other outputs of the command apparatus, the signals are 0 (y_2, y_3, …, $y_n = 0$). The signal, which is equal to 1, also enters the control chambers of the distributor 2 of the first cell and the distributor 1 of the last cell, fixing their initial state, at the input of the distributor 2 of the next second cell and at the input of the distributor 2 of the first cell. Through the distributor 2, the signal, which is equal to 1, passes through the element $\vee$ to the control chamber of the distributor 1. This ensures that the output signal is stored $y_1 = 1$ after the signal is removed p_n. When the input of the second signal cell is applied $x_2 = 1$ the distributor 2 of the second cell is switched and the signal enters the control chamber of the distributor 1 of the same cell, switching the distributor 1. The supply pressure through the distributor 1 of the second cell enters the output of the second cell of the command apparatus ($y_2 = 1$) and into the control chambers of the distributor 2 of the second cell and the distributor 1 of the first cell by switching them. After switching the distributor 2 of the second cell in the starting position, the signal, which is equal to 1, passes through this distributor to the control chamber distributor 2 this the same cells. In this case, the signal, which is equal to 1, is stored at the output ($y_2 = 1$). At the same time, the distributor 1 of the first cell returns to its original position under the action of the backwater spring and the signal $y_2 = 1$, which enters the inverse control chamber of the distributor 1 of the first cell. At the same time, the output signal y_1, as with other outputs, signals $y_3, y_4, …, y_n$, are equal to 1. Further signaling x_n causes a signal to appear y_n, which is equal to 1, at the output of the last cell. At the last outputs, the signals are equal to 0, the work of the command apparatus here is similar to the work of the cells under consideration. The cycle of operation of the command apparatus resumes when a signal is applied $x_1 = 1$ into the control chamber of the distributor 2 of the first cell. In the event of a removal of the supply pressure, including in an emergency, the command apparatus is set to the initial state due to the use of distributors with backwater springs.

The reprogrammable complex command apparatus (a.s. no. 1241217) is shown in Fig. 4.

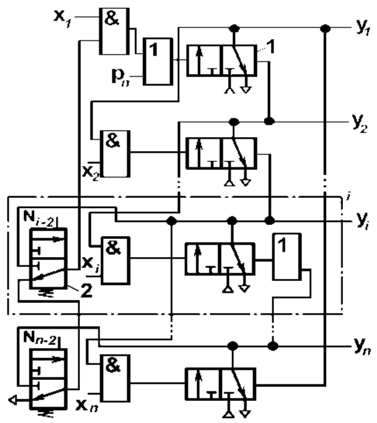

Fig. 4. Scheme of the reprogrammable command apparatus

The command apparatus works in this way. During the start signal p_n through the $\vee$ the allocator 1 of the first cell is switched. A signal is generated in the output channel of this cell $y_1 = 1$. At the other outputs, the signals are 0. The signal from the output of the distributor 1 of the first cell enters the element $\wedge$ the second cell, and when the signal is given $x_2 = 1$ the distributor 1 of the second cell is switched and a signal is generated $y_2 = 1$. At the same time, the signal from the output of the distributor 1 of the second cell turns off the distributor 1 of the first cell; output $y_1 = 0$ etc. If you need to get *n* output signals are fed to the tuning input ($N_{i-2} = 1$) into the control chamber of the distributor 2 of the last cell. In this case, the signal from the output of the distributor 1 the last cell through the distributors of 2 cells and fed to the input of the element $\wedge$ of the first cell. The cycle repeats when the signal is applied $x_1 = 1$. If you want to get a smaller number *u* output signals of the command apparatus, the signal is fed to the tuning input N_{i-2}($N_{i-2} = 1$). Here, a sequence that contains any number is implemented *n* and less, up to three operations.

Main results. In Fig. 5 provides a sheme of a pneumatic command apparatus (patent on application no. U202300879) containing *n* cells, each of which contains a two-position three-line distributor 1, which has two control chambers, closed and normally open channels, and an output channel. Moreover, the closed channel of the distributor of the first cell is connected to the power source, and the normally open channels of all distributors are connected to the atmosphere. There are also OR valves 2. The output channel of the distributor of the next cell is connected to the right control channel of the distributor of the previous cell. The inputs of the command apparatus receive the input signals of the corresponding cells, and the output signals of the commands of the opparat are received from the output channels of the distributors of the corresponding cells. The output channel of the distributor 1 of each cell is connected to one valve inlet OR 2 of the same cell, and is also connected to the closed channel of the distributor of the next cell. The other valve input OR 2 of each cell is connected to the input signal of the corresponding cell. A spring is installed in the right control channel of all distributors. The operation of the pneumatic command apparatus is as follows: when an input signal is applied X1 = 1 the allocator of the first cell is switched, while Y1 = 1, this signal enters the upper input of the valve OR of the same cell, keeps the distributor on, into the closed channel of the distributor 1 of the second cell and the control channel with the spring of the last cell. Further, when the input signal is given X2 = 1, switches the allocator 1 of the second cell, while Y2 = 1, also enters the chamber with the spring of the distributor 1 of the second cell, while Y1 = 0, to the upper inlet of the valve OR of the same cell, holding the distributor in the on state, and the closed channel of the distributor 1 of the next cell. Thus, let's move on to the cell *n* – 1. The input signal is then applied Xn–1, in this case, the distributor 1 of the penultimate cell is switched, and the signal at the output Yn–1 = 1, this signal is sent to the upper inlet of the valve OR of the same cell, keeping the distributor on, and to the closed channel of the distributor 1 of the last cell and to the chamber with the spring of the distributor 1 of the previous cell, and so on to the second cell, while Y2 = 0. Further, when the signal is given Xn = 1, the allocator of the last cell is switched, while Yn = 1, which enters the upper inlet of the valve OR of the same cell, keeping the distributor on, and into the spring control channel of the distributor of the penultimate cell, with the signal Yn–1 = 0. Further the operation of the command apparatus is repeated when the input signal is applied X1 = 1. When designing, we use the approach and methods proposed by M. Cherkashenko [1–4].

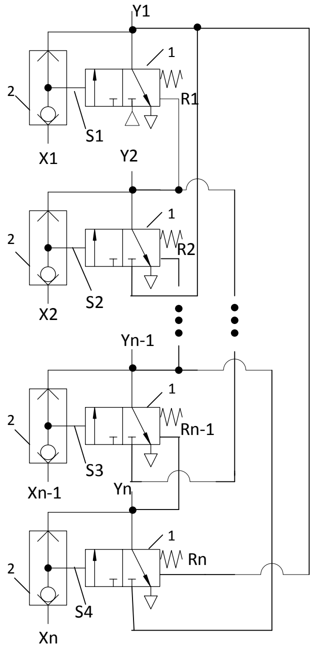

Fig. 5. Command apparatus

Consider the design of a pneumatic control system for a molding machine. The actuators of the machine are pneumatic cylinders (C_1–C_5), which correspond to outputs *Z*1 – *Z*5, vibrators *B*6 and *B*7 (outputs *Z*6 and *Z*7) and a nozzle for blowing mold *C*8 (output *Z*8) (Table 1). Cylinder C_1 raises and lowers the flask, and the lower starting position is controlled by the limit switch *X*7, and the upper position is final switch *X*8. Cylinder C_2 performs prepressing, the initial position of the cylinder is controlled by the limit switch *X*5, and the final position is controlled by a time relay τ (*Z*2) (the setting of which determines the duration of pre-pressing). Cylinder C_3 is used to perform broaching. The cylinder C_4 pushes the gate back, which leads to the filling of the flask with the molding mixture, and the initial position of the gate is controlled by the limit switch *X*9, and final – *X*10. The cylinder C_5 puts the crosshead in the working position, which is controlled by the limit switch *X*11. The operation cycle begins with pressing the start button (*X*1 = 1), as a result, the lock moves up (*Z*1 = 1) and stops in the upper position. Then, at a signal (*X*8 = 1), the vibrator is turned on (*Z*7 = 1) and the gate is extended (*Z*4 = 1), while the molding sand fills the flask, and then at the signal (*X*10 = 1) the gate returns to its original position. On signal (*X*9 = 1) the vibrator is turned off (-*Z*7 = 1) and the flask is lowered (-*Z*1 = 1). Then, at a signal (*X*7 = 1), the traverse is set to the working position. At the signal (*X*11 = 1), the stub rises (*Z*1 = 1) and pre-pressing takes place (*Z*2 = 1), the duration of which is controlled by a time relay, on a signal τ (*Z*2) = 1, from which the flask

Table 1 – Interaction of input signals and actuators

Output signals		*Inputs signals*					
		Automatic Mode				*Adjustment*	
				Intermediate			
Designation	*Name*	*Starting position*	*Final position*	*Naming*	*Designation*	*Included*	*Closed*
*Z*1	Moving the flask	*X*7	*X*8	–	–	–	–
*Z*2	Pre-pressing	*X*5	τ (Z2)	–	–	–	–
*Z*3	Broach	–	–	–	–	–	–
*Z*4	Moving the gate	*X*9	*X*10	–	–	–	–
*Z*5	Moving the crosshead	–	*X*11	–	–	–	–
*Z*6	Shaking the flask	–	–	–	–	–	–
*Z*7	Shaking the hopper	–	–	–	–	–	–
*Z*8	Blowing molds	–	–	–	–	*X*4	–

descends (-*Z*1 = 1), pre-pressing is coming to an end (-*Z*2 = 1), the broach cylinder is extended (*Z*3 = 1) and the flask vibrator is switched on (*Z*6 = 1). At the signal *X*5*X*7 = 1, the traverse returns to its original position (-*Z*5 = 1) and the shaking the flask vibrator turns off (-*Z*6 = 1). After that, the operator manually turns on (*X*4 = 1) mold blowing (*Z*8 = 1) and disables the broach (-*Z*3 = 1). The cycle ends. Device: *X*1 – start button; *X*4 – mold blowing button.

The operation graph [5, 6] is shown in Fig. 6.

For the synthesis of the scheme, it is advisable to use the approach proposed by M. Cherkashenko.

The mapping matrix is presented below.

Here, the bold units on the main dial (shifted by one line) of the matrix of correspondences correspond to transitions; the underlined contradictory unit is eliminated; the remaining units are not contradictory. Elongations are shown in bold, and identical input sets are marked with asterisks. The matrix of correspondences defines the correspondence between the signals that cause the transitions and the complete input sets that act in the transitions. Analysis of the matrix of correspondences made it possible to identify and eliminate contradictory transitions. On the basis of the elongations carried out, a system of equations describing the scheme of the control system is synthesized. Further, minimization is performed due to factorization and decomposition of equations, and obtaining equations in final form.

$S_1 = w = \bar{z}_7 = x_9 y_3$; $S_2 = \bar{z}_2 = z_3 = z_6 = \tau$;

$S_3 = \bar{z}_3 == z_8 = x_4$; $R_1 = y_2$; $R_2 = y_3$; $R_3 = y_1$;

$z_1 = x_1 + x_{11}$; $\overline{z_1} = w + \tau$; $z_2 = x_{11}$;

$z_4 = z_7 = x_5 x_8$; $\bar{z}_4 = x_{10}$;

$z_5 = x_7 y_1$; $\bar{z}_5 = \bar{z}_6 = x_5 x_7 y_2$;

$z_8 = x_4$ – blowing molds.

The diagram of the pneumatic control system of the molding machine is shown in Fig. 7.

It should be noted that the methods of designing circuits are presented in [7–12].

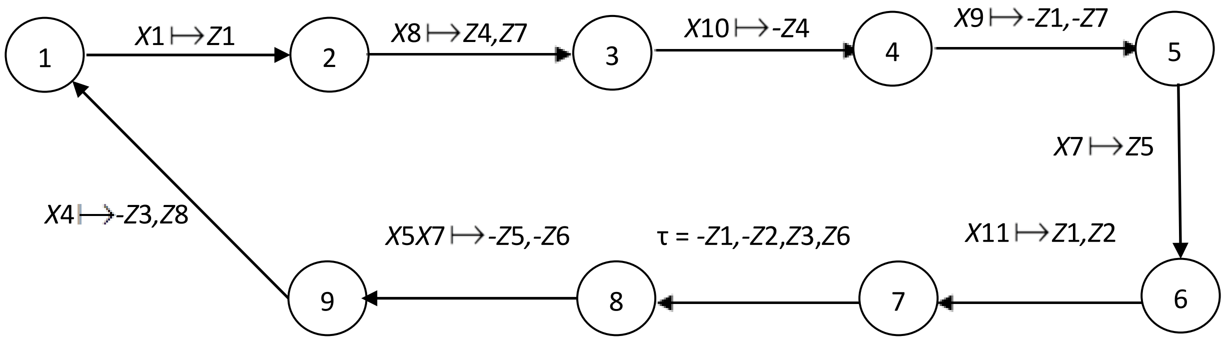

Fig. 6. Graph of operations: -*Z* – signal to return the cylinder rod to its original position

	x_1	$x_8\boldsymbol{x_5}$	x_{10}	$x_9\boldsymbol{y_3}$	$x_7\boldsymbol{y_1}$	x_{11}	$\boldsymbol{\tau}$	$x_5x_7\boldsymbol{y_2}$	x_4
$\emptyset, x_5x_7x_9 \to \emptyset$ *	0	0	0	1	0	0	0	0	0
$x_1, x_5x_7x_9 \to z_1$	**1**	0	0	1	0	0	0	0	0
$x_8, x_5x_9 \to z_4z_7$	0	**1**	0	1	0	0	0	0	0
$x_{10}, x_5x_8 \to \bar{z}_4$	0	1	**1**	0	0	0	0	0	0
$x_9, x_5x_8 \to \bar{z}_1\bar{z}_7S_1$	0	1	0	**1**	0	0	0	0	0
$x_7, x_5x_9 \to z_5$ *	0	0	0	0	**1**	0	0	0	0
$x_{11}, x_5x_7x_9 \to z_1z_2$	0	0	0	0	1	**1**	0	0	0
$\tau, x_8x_9 \to \bar{z}_1\bar{z}_2z_3z_6S_2$	0	<u>1</u>	0	0	0	0	**1**	0	0
$x_5x_7, x_9 \to \bar{z}_5\bar{z}_6$ *	0	0	0	0	0	0	0	**1**	0
$x_4, x_5x_7x_9 \to \bar{z}_3z_8S_3$	0	0	0	1	0	0	0	0	**1**

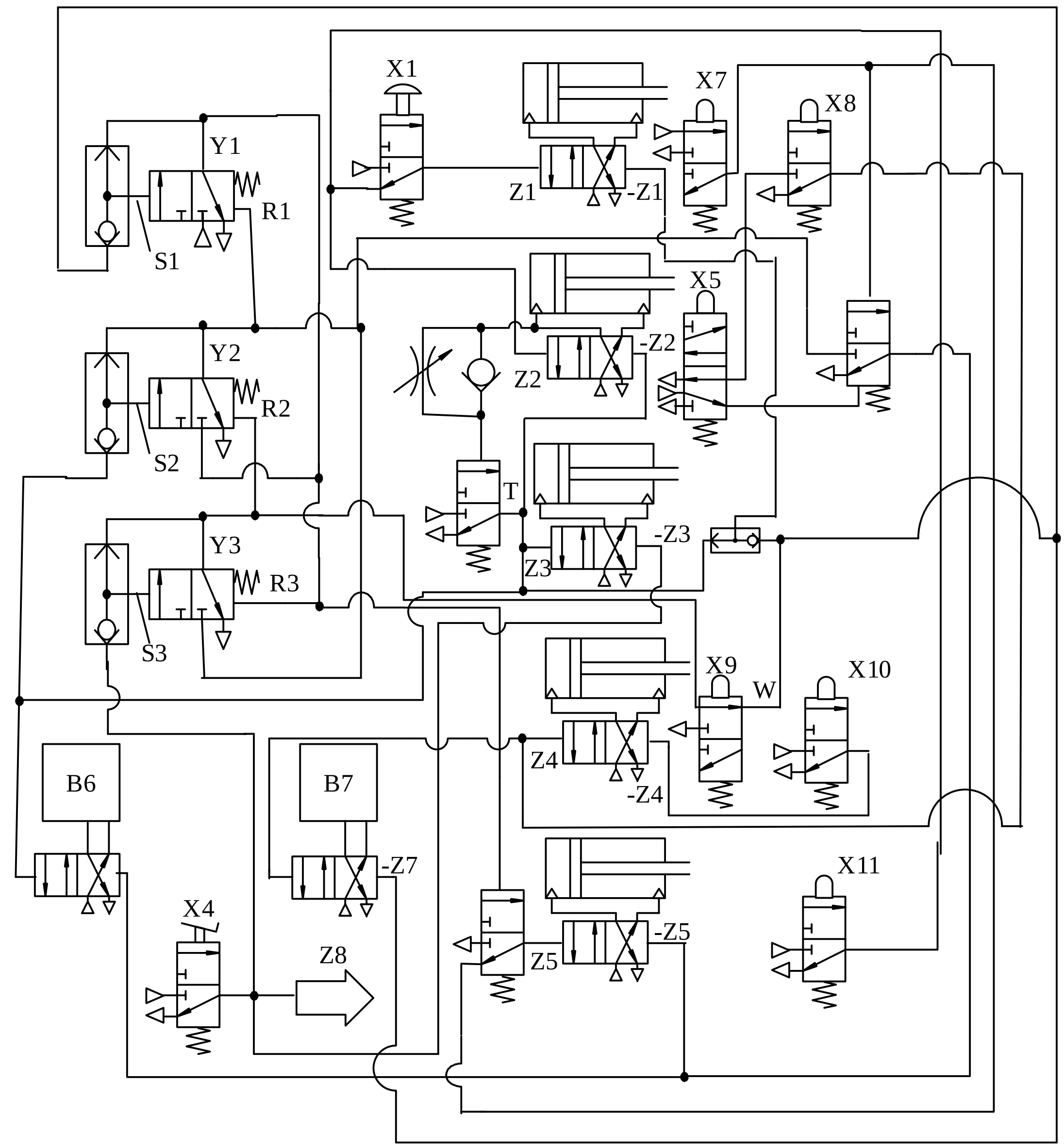

Fig. 7. Scheme of the pneumatic control system of the molding machine: T-signal from the output of the time relay

Findings. Thus, the use of the proposed command apparatus, the difference from the existing schemes of command apparatuses, makes it possible to reduce by a third the number of distributors in the synthesis of the command apparatus itself and significantly reduce the number of elements when using the chosen approach to the design of circuits of pneumohydraulic control systems. Note that the minimized scheme contains 9 devices for its implementation, instead of 32 using the standard method, i.e. 3.5 times less.

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