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SYSTEMS ENGINEERING DESIGN AND DEVELOPMENT OF UNIVERSAL DIE SET FOR HYDRAULIC PRESSES

Purpose. Improvement of the universal die set (UDS) design for hydraulic presses based on system engineering and morphological synthesis of technical solutions.

Methodology. System engineering methods were used in the development of the universal die set. This approach made it possible to formulate requirements and choose high-quality technical solutions. Stages of analysis and step-by-step design of nodes are identified and implemented. The stages of analysis and step-by-step design of nodes were identified and implemented. Classification of the types of connections of the construction elements of the UDS has been carried out. Contiguity matrices were constructed to describe the connections between elements of the UDS. This made it possible to formalize admissible combinations of node construction. The stages of the structure's operation are defined using a state diagram for the stamping process. Different variants of the cycle of the press with varying ways of pushing the forgings out of the matrix are considered and given.

Findings. A set of subsystems for UDS was developed, taking into account the expansion of the technological capabilities of hydraulic presses when implementing technologies with more complex kinematics than stamping processes that are usually used on hydraulic presses. The process of selecting UDS elements has been formalized. The expansion of the technological capabilities of universal hydraulic presses due to the adopted constructive decisions is shown.

Originality. The design of the universal die set for hydraulic presses is based on the application of systems engineering methods is improved. The expansion of the technological capabilities of hydropresses was carried out on the basis of the proposed classification of the types of UDS structural elements connections and presses. Matrixes of permissible combinations of element connections have been developed for the selection of connections between the elements of the UDS construction. State diagrams have been developed for various options for the implementation of technological processes.

Practical value. A methodology for applying systems engineering methods to the design of a UDS for hydraulic presses has been developed. It is shown that the application of system engineering methods allows for a guaranteed improvement of their technological capabilities. Based on this approach, the design of the UDS was developed to fit various work options. Using additional locking mechanisms to temporarily limit the mutual movement of the block and press elements allows the use of the main cylinder and the slave cylinder of the hydraulic press to perform various technological operations. This approach provides a more complex sequence of technological operations for manufacturing parts. An example of the application of the developed design of the UDS for the process of severe plastic deformation (SPD) by the method of reversible shear is presented.

Keywords: *system engineering, universal die set, "press-die set" system*

Introduction. Systems engineering technologies for creating new technical objects based on models and design languages allow generalizing approaches to product design. This ensures the high quality of developed technical solutions and their justification. Production demand requires a transition to the development of modular, upgradeable, and reconfigurable solutions for hydraulic systems using modern technologies. Innovative approaches are being developed to implement the concept of a multi-agent control system for smart hydraulic presses [1].

To obtain deformed semi-finished products in small-scale production, it is advisable to use a hydraulic press with universal technological equipment. It should allow the processing of blanks from alloys of iron, titanium, copper, aluminum, and other alloys for various purposes, as well as blanks from powder materials. In view of this, the design of a promising installation should meet the requirements for ensuring the possibility of implementing a number of technological processes (TP) with a different sequence of operations and extended tool kinematics. However, universal presses, in this case, do not fully satisfy the requirements for performing a sequence of technological operations. This is especially important if the operations must be performed at one technological position.

Literature review. A significant amount of research has been conducted in the field of technological processes of metal processing by pressure, the structure and properties of workpieces obtained by various forming methods. At the same time, the number of works devoted to the development of a methodology for designing tools and equipment for performing technological processes is limited [2, 3]. Experimental and industrial implementation of metal processing technologies by pressure largely depends on the kinematic capabilities, quality of design, and manufacturing of dies. These factors determine the efficiency of the process of deformation and removal of products from dies. In a number of technological operations, especially when pressing powder materials, a large stroke of the working tool is required. In addition, the stroke of the ejector cylinder is not always sufficient to perform technological operations. Therefore, the press is selected with an excess of the nominal force required for the technological process. With an increase in the level of technological complexity of the process, the kinematics of the movement of the working tool also becomes more complicated.

For example, in order not to destroy powder blanks after pressing, a certain sequence of movements of the matrix and punches is necessary. Another group of promising processes for industry is SPD [4, 5]. Today, these processes are actively studied and introduced into industry. The reason for the increased attention to them is the possibility of obtaining new materials with high mechanical characteristics and a number of other unique properties [6]. Large strains and SPD are two widely known approaches to processing metal blanks, which differently affect the microstructure and physical and mechanical properties of materials [5]. They also allow for the implementation of energy-efficient and resource-saving technological processes for obtaining materials of different classes, including high-gradient materials with an ultrafine-grained structure [4, 7] and architectural materials [8]. A significant part of the existing SPD methods uses various types of extrusion as the main metal forming process, namely equal-channel angular pressing [9] and twisting [10]. Another group of SPD processes is based on multiaxial forging (multidirectional forging) [11] and reverse shearing [12].

Analysis of the requirements for the kinematics of a number of methods of metal processing by pressure shows that universal hydraulic presses do not have a sufficient number of degrees of freedom for their implementation. This leads to the need to design special expensive equipment and, thus, makes it economically impractical to introduce technologies based on SPD methods in industry in conditions of single and small-scale production. At the same time, a number of technical limitations can be circumvented by improving the design of the UDS.

To assess the effectiveness of design solutions, the methodology given in [13] can be used. The index (coefficient) of the unification of design solutions can be calculated as the ratio of the number of unified elements to the sum of additional design elements for each of the technological processes. Additional complexity of the design can be estimated as the ratio of the number of additional design elements in the design to the number of unified elements. The rational value of the unification coefficient for die tooling is a value greater than 0.6.

To automate the design of die equipment for MPP processes, highly specialized CADs are used with an orientation to individual processes, such as rolling, bending, straightening, and other sheet metal processing operations [14]. Much less development is related to the design of die for volume forging, trimming [15, 16], and extrusion operations. Some CADs support equipment from individual manufacturers, which significantly reduces modeling capabilities.

In recent years, there has been an intellectualization of the design of die equipment for sheet metal processing processes by building CAD using neural networks and other artificial intelligence methods [17, 18]. This makes it possible to obtain more rational solutions and find promising combinations based on the experience of past developments, combining the influence of parameters, the relationship between which is not obvious.

The development of complex technical systems requires the use of systems engineering to achieve well-designed solutions [13]. In many situations, systems engineering includes several stages: requirements definition, conceptual design, engineering design, modeling, testing, and implementation in production [19]. ISO offers several systems engineering standards, including important system life cycle stages, software design processes, quality assurance, and process management [20]. Depending on the type and specifics of the project, MBSE (Model-Based Systems Engineering) approaches and models developed by the OMG consortium can be used to achieve the goal of systems engineering. Systems engineering methods are applied when creating complex systems using models based on the SysML language to support all life cycle stages [21]. In particular, the Automotive SPICE model has proven itself well in the automotive industry [22]. The CMMI (Capability Maturity Model Integration) model is used in various areas [23]. The V-Model approaches software development by performing verification and validation at each stage of the project life cycle [24]. The Agile methodology is applied to software development and emphasizes an iterative approach, collaboration, flexibility, and rapid response to change [25, 26]. The Ad hoc model is suitable for developing systems characterized by a lack of formal structure and processes [27].

In the design methodology proposed by the authors earlier, issues of choosing types of technical solutions for elements of the designed system and their connections are considered [13, 28]. Such a methodology for selecting elements is important for any designed structure, as it ensures its operability and reliability and reduces economic costs. The choice can be made on the basis of creating classifications of technical solutions for elements used in structures and determining the rules for their selection in specific situations [28].

The structure of the UDS system can be represented as a matrix of adjacency of structural elements. These elements are moved by the working cylinders of the press or are mounted on the frame. The cells of the table indicate the type of connection between the structural elements.

The main problem in developing a UDS is to ensure its modification for different TP. Another problem is the selection of element parameters, which take into account the requirements set by technological processes.

Purpose. The purpose of this work is to improve the design of a universal die set for hydraulic presses based on systems engineering and morphological synthesis of technical solutions.

Selection of design solutions for UDS. Analysis of the installation operation cycle when implementing the SPD processes, extrusion with counterpressure, and pressing with active friction forces showed that the number of operations in these cases exceeds the capabilities of their performance by power cylinders of universal hydraulic presses. Therefore, when developing a UDS, it is of some interest to provide a temporary connection of UDS elements with press elements. This allows for the sequential performance of various operations by press cylinders. In particular, the main press cylinder can be used first for forging the workpiece and then for its ejection, taking into account the necessary kinematics of the movement of the lower punch of the die set.

To expand the functionality of the press, it is necessary to implement a change in the structure of the connections of the UDS elements to provide the possibility of temporary limitation of the axial movement (fixation) of the UDS parts relative to the moving parts of the press or the frame. For this, it is necessary to switch the operation of the working cylinders based on changing the connections between the elements of the "press-die set" system. This will allow for the changing of the kinematics and ensure the execution of a given sequence of operations. Thus, the main principle of the design solution to this problem is a temporary mechanical fixation of the parts of the device relative to the moving parts of the hydraulic cylinders or relative to the stationary press frame. The mechanical connection with the hydraulic cylinders allows you to move and load the elements of the UDS structure. In this case, some structural elements are fixed in a given position relative to the frame to move or transfer the load to other elements.

The choice of connections between structural elements is carried out depending on the sequence of operations of the technological cycle and the need to switch the drive. The drive must perform both main and auxiliary operations. In particular, the ejector cylinder can create active friction forces when pressing powders and then push out the resulting workpiece, which expands the press's capabilities.

Let us consider the transition from the TP operations sequence to the UDS design. It should be noted that depending on TP, a number of design options for connecting UDS elements are possible. Therefore, a classification of the types of connections between UDS elements and the press (Fig. 1) is proposed according to the degree and nature of the restriction of the movement of the elements relative to each other. All loads from the drive side are carried out along one axis since the cylinders are located symmetrically relative to the press axis. In this regard, limiting the types of considered connections between the matrix elements and the press is possible.

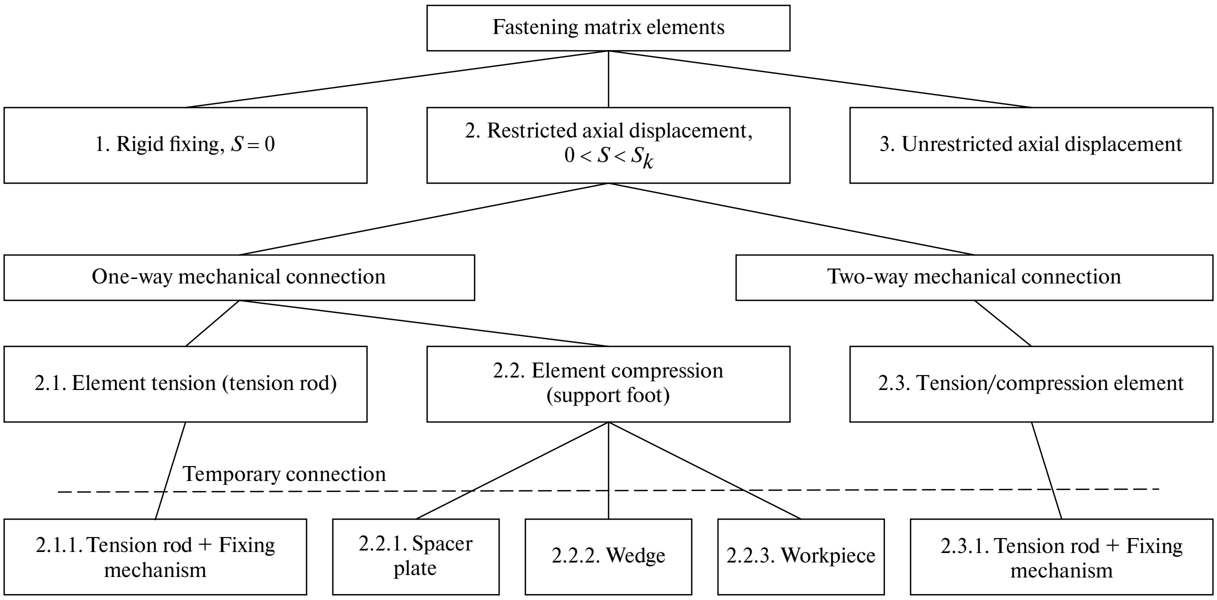

Fig. 1. Taxonomy of types of connections of structural elements UDS and press:

S – the value of the relative displacement of the connected elements

The set of types of DC connections (structural constraints) between the UDS structural elements and the press is a set of sets $DC = \{\{1\},\{2\},\{3\}\}$, where the separation is performed according to the principle of limiting the relative movements of the UDS elements (Fig. 1).

Rigid fastening *1* (Fig. 1) assumes no movement of elements along the axis of the die. In this case, the value of the relative movement of the elements being connected is $S = 0$. Limited axial movement *2* allows you to coordinate the kinematics of the movements of the elements connected to the drive and the die. For example, usually, the stroke of the main cylinder is much longer than the stroke of pressing and pushing, so it must be limited if the working cylinders are used to move the lower punch and push the stamped product out of the die. One-sided and two-sided mechanical connection transmits the load in one or two directions, respectively. The possibility of unlimited axial movement *3* is implemented, for example, between the columns and the bushings of the block, while axial loads do not arise.

The connection between two UDS elements can be implemented using various designs. When making a one-sided or two-sided connection, the elements that provide the transmission of axial loads can work in compression or tension. Various rods *2.1* (Fig. 1) work in tension; they are equipped with mechanisms for fastening UDS parts *2.1.1:* clamps and nuts that transmit tensile forces. The compressive load is perceived by the pressing stroke limiters *2.2*: adjustable spacer plates, wedges, or blanks. During compression, the force is usually transmitted by the end surfaces of the structural elements or locked between them.

For example, in addition to pushing out the forging by a separate cylinder, the design of presses and dies also uses a method for pushing out forgings using a frame structure 1–4 (Fig. 2) [14]. In this case, rod *4* connects the upper *1* and lower *3* movable die plates and forms a movable frame.

When pushing out forgings using a frame structure, the lower movable plate *3* of the frame is installed under the press Table 2, on which the die *5* is installed, and is connected by rods *4* to the press slider *1.* The ejector *6* is installed on the movable plate *3.* After stamping the forging *8* with punch *7*, slider *1* moves up and pushes the forging out of die *5.* In this case, the ejector cylinder is not used.

Let us consider the behavior of the "press-stamp" system for the stamping process using a frame structure for pushing out forgings [14]. In this case, the system's operation can be represented in the form of a state diagram, which demonstrates the sequence of stamping operations and the transitions between them (Fig. 3).

In this case, several system (states *0, A – D)* associated with the movement of the moving parts of the press can be distinguished. The work begins in an arbitrary position of the moving parts of the press (states *0.1* and *0.2*). Then the slider

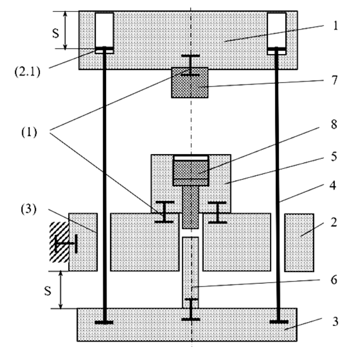

Fig. 2. Scheme of installing the ejector on a moving frame:

1 – slider, 2 – press table; 3 – lower moving frame plate; 4 – rods; 5 – matrix; 6 – ejector, 7 – punch; 8 – forging; 1, 2.1, 3 – indices of types of connections of structural elements, shown in Fig. 1

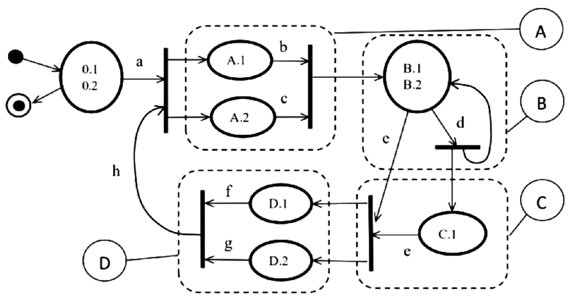

Fig. 3. State diagram for TP stamping using a frame for ejecting forgings. Indices:

1 – slider with frame; 2 – ejector; states: A – slider movement to the starting position; B – stand for installing the workpiece; C – stamping; D – slider movement up, ejecting the forging from the die; a–g – events that initiate transitions between UDS states and the ejector move (event a, state *A*) to the starting position and stop to load the workpiece (state *B*). The TP cycle is prepared. Then, according to the command *d*, the slider moves down, and stamping is performed (state *C*). The ejector is in the lower position (state *B.2*). When the press slider moves up (event *e*, state *D*), the matrix opens, then the ejector starts to move up (state *D.2*). Due to the kinematic connection between the slider and the movable frame cross member, the forging is pushed out of the die. After this, another partial stroke of the slider with the frame down is performed (event *h*, state *A*) to return the slider and the ejector to the starting position for loading a new workpiece (state *B*) and repeating the cycle. Thus, the full stroke of the slider must be longer than or equal to the sum of the working stroke and the ejector stroke.

Let us depict the structure of the UDS in the form of an adjacency matrix $A = \{a_{ij}\}$, which is used to represent finite graphs $G = (V, E)$, where V is the set of nodes – structural elements, E is the set of element links, in this case, ordered in the form of a taxonomy (Fig. 1). The adjacency matrix of the frame structure of the forging extrusion (Fig. 2) is given in Table 1; it shows the main structural elements of the press and the UDS (V_i), as well as their connections.

The elements of the die, such as the matrix *5* (Fig. 2), can be installed either stationary relative to Table 2 of the press or connected to the movable elements of drive *1, 3, 4, 6, 7*. In particular, the upper punch *7* is rigidly connected (connection type *1*) (Fig. 1) to plate *1* and the slider, which is driven by the main cylinder of the hydraulic press. The matrix *5* is installed stationary (connection type *1*) relative to the table and the press frame *2*. The ejector *6* is installed on the lower movable plate *3*, which moves upward together with the slider of press *1* during the return stroke. The movement of the ejector *6* with plate *3* occurs due to the presence of rods *4* connected to the slider (connection type *2.1*). The lower movable plate *3* is located under Table 2 with a gap *S*. Therefore, it has limited movement (connection type *2.2*).

To provide information for this conceptual design stage, we present a generalized adjacency matrix, which includes a set of possible types (variants) of connections between elements (Table 2). The matrix is filled in according to the results of expert assessment and includes a set of permissible connections that can be applied. The elements of the “press-die set” system in the detailing process are supplemented with additional UDS plates (upper movable plate *V5,* lower and upper fixed plates *V7, V9*, lower cylinder rod *V6*, and central rod *V4.* For example, the latter is part of the working tool when deforming tubular blanks or powder materials. The rod does not transmit vertical force but only limits the working cavity of the matrix.

Construction of parametric and geometric models UDS. At the next design stage, solid models are built, and design options for a specific die and TP are checked, considering the specified constraints. Then, a parametric UDS model is developed, and the equipment’s capabilities for performing TP operations, ensuring the specified values of tool movement, force mode of deformation, dimensions of the press workspace, and other constraints are checked. If necessary, alternative UDS design solutions and types of element connections or another press are selected.

UDS development results for universal hydraulic presses. The developed design is based on practical experience in designing and operating similar installations [10]. To ensure the reliable and durable operation of the UDS, a number of new technical solutions and modifications of the main subsystems were applied [12, 29]. This die set significantly expands the technological capabilities of hydraulic presses by modifying the connections of elements with their moving parts. The general view of the proposed UDS for several processes of deformation of workpieces is shown in Fig. 4. The die set design is designed considering the possibility of processing high-strength aluminum and titanium alloys.

The die set includes four paired plates: *1, 4,* and *2*, *3*. The upper movable plate *1* is fixed on the press slide. The fixed lower plate *2* is installed on the press table and is connected through supports *5* to plate *3*. Thus, plates *2* and *3* form a fixed base of the die set. The connection and arrangement of plates *1* and *3* relative to each other and the working tool is carried out using rods *6* and bushings *7*. The rods provide centering of the working tool independently of the press.

On plates *1* and *3,* there are universal mounting points for the upper punch *8* and the matrix *9*, respectively, which ensures quick tool change. Plates *1, 4*, and rods *6* form a power frame for moving the lower punch, placed on plate *4*, with the help of which the forging is pushed out of the matrix.

In addition, the UDS contains a mounting assembly for the ejector on rod *10* of the lower cylinder of the press. Temporary fixation of the position of the movable plate *4* relative to other structural elements is carried out by wedges *11*, stops *12*, and fix-

Table 1

Adjacency matrix for UDS with a frame structure of forging extrusion

Structural elements (Fig. 2)	Types of relationships a_{ij} (Fig. 1)						
	1	2	3	4	5	6	7
1. Slider and upper movable plate	0	2.2	–	2.1	–	–	1
2. Press table	–	0	2.2	3	–	–	–
3. Lower movable plate	–	–	0	1	a_{ij}	1	–
4. Tie rods	–	–	–	0	–	–	–
5. Matrix	–	–	–	–	0	2.2	2.2.3
6. Ejector	–	–	–	–	–	0	–
7. Punch	–	–	–	–	–	–	0

Table 2

The adjacency matrix of permissible options for connecting UDS elements to the press

Structural elements	V1	V2	V3	V4	V5	V6	V7	V8	V9
V1 Matrix	0	2, 3	2, 3	3	–	–	1	1	1, 2.2
V2 Upper punch	–	0	2.2	3	1	–	–	–	–
V3 Ejector	–	–	0	–	–	1	–	1, 2.2	2.2
V4 Center rod	–	–	–	0	–	1	–	1	–
V5 Slider and upper movable plate	–	–	–	–	0	2.2	2.2	2	2.2
V6 Lower cylinder rod	–	–	–	–	–	0	–	1, 2, 3	–
V7 Table and lower fixed plate	–	–	–	–	–	–	0	2.2	1
V8 Lower movable frame plate	–	–	–	–	–	–	–	0	2.2
V9 Upper fixed plate	–	–	–	–	–	–	–	–	0

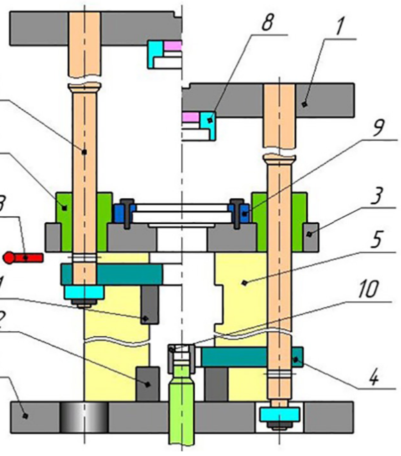

Fig. 4. General view of UDS hydraulic presses:

1, 4 upper and lower movable plates; 2, 3 – upper and lower fixed plates; 5 – supports; 6 – rods; 7 – bushings; 8, 9, 10 – fastening units of the upper punch, matrix, and ejector, respectively; 11, 12 – wedges and stops for fixing the plate 4 in the upper and lower positions, respectively; 13 – fastening elements of the plate 4 on the rods 6

ing elements *13*. These elements are used depending on the implemented TP. The presence of two options for ejecting the workpiece and several fixing mechanisms allows you to create variants of the UDS design for a number of metal processing processes by pressure, including for SPD processes of workpieces.

The transmission of the working force to the lower plate *2* and the press table is carried out through the intermediate plate *3* and vertical supports *5*, which makes it possible to remove the workpiece from the bottom of the matrix (above the lower plate *4*). The rods *6* act as guide columns between the upper movable plate *1* and the fixed plate *3*. The installation of the sleeves *7* significantly improves the positioning of the working tool. The design of the elements that provide temporary fixation of the UDS elements allows you to automate their installation and removal. These solutions improve the productivity of the UDS.

Example of using UDS for SPD by reverse bias method. The application of the described design algorithm is shown in the example of developing a UDS that allows the implementation of SPD processes on universal hydraulic presses. Let us consider an example of using UDS to implement SPD by the reverse shear (RS) method [12]. This process includes a number of repetitions of the workpiece deformation in the die to obtain an accumulated degree of deformation $e = 3$ and more. For its implementation, deformation with the return of the workpiece directly in the die cavity is used. This approach improves the temperature regime of the die and the workpiece, automates the cycle, and increases productivity.

The state diagram for the RS process with a given number of operations (Fig. 5) shows the sequence of the primary process states (*A, B, C, D*), similar to the TP of stamping using a frame structure for pushing out forgings (Fig. 3). This indicates the generalizability of the TP implementation using UDS.

An example of the constructive implementation of UDS for SPD by the RS method is shown in Fig. 6. The process is performed in a series of stages of deformation and rotation of the workpiece *17* in the cavity of matrix *12*. The rotations are carried out by the side ejector *15* mounted on the movable plate *4*. After n compressions, the workpiece is removed from matrix 1 by the lower workpiece ejector *16*, which is fixed on the rod of the lower cylinder *10* of the press. The side ejector *15* is also in the upper position, which allows you to install and hold a new workpiece in the desired position when moving the slider down. Thus, during operation, ejector *15* has two upper positions: after the workpiece is rotated in the matrix and after the workpiece is removed at the end of processing.

The operation of the press is similar to the previous case considered earlier (Fig. 3) with the exception of the use of an additional lower ejector 16 connected to the lower cylinder *10*. During operation, the UDS passes through a series of successive states *A–D*. After n stages of deformation of the workpiece, the slider, the upper plate *1*, the punch *13*, and the side ejector *15* move (event *e*, state *D*) upwards. The ejector *16* also moves upwards (event *k*, state *5.3*) and removes the forging *17* from die *1*. After that, the system returns to its original state (event *n*, state *A*).

The coefficient of unification of design solutions for the given example of UDS for the implementation of the RS process, calculated according to the method [13], is *1.2*. The value of the coefficient of additional complication of the UDS structure when implementing screw extrusion is *0.2*. The calculated values of the coefficients confirm a sufficient level of unification of the developed UDS design.

Conclusions. The analysis of the experience of operating similar installations showed that the complexity of the workpiece deformation schemes is due to the use of backpressure, active friction forces, execution of the stamping cycle at one technological position, etc. This analysis made it possible to determine the directions of UDS improvement, as well as to

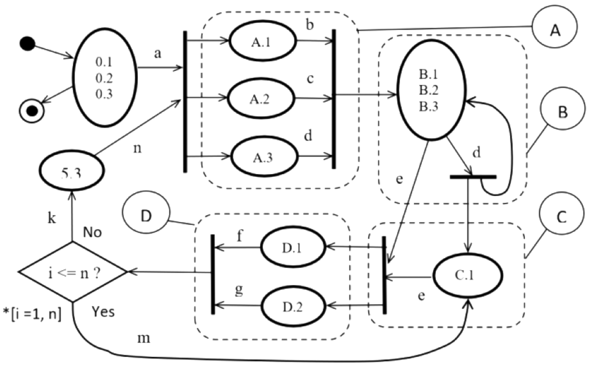

Fig. 5. State diagram for TP by RS method with a decomposition of basic states:

1 – slider with a frame; 2 – side ejector, 3 – bottom ejector; 0, A – D - states; a–n – events

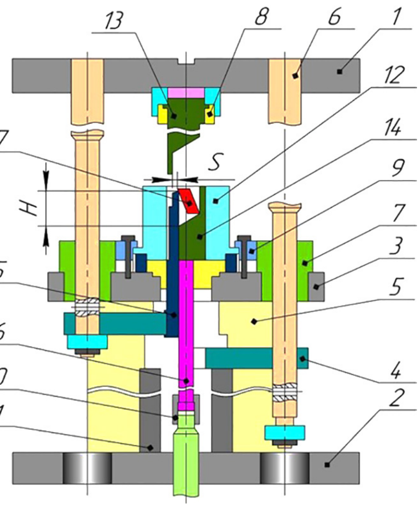

Fig. 6. General view of UDS for SPD blanks according to the scheme of reversible cutting on hydraulic presses:

1, 4 – upper and lower movable plates; 2, 3 – upper and lower fixed plates; 5 – supports; 6 – rods; 7 – sleeves; 8, 9, 10 – fastening units of the upper punch, matrix, lower ejector, respectively; 11 – stops; 12 – matrix; 13, 14 – upper and lower punches; 15 - lateral ejector of the workpiece rotation; 16 – lower ejector; 17 – workpiece justify the need to change the connections in the "press-die set" system for the implementation of various metal processing processes by pressure. As a result, a set of subsystems for UDS was developed in order to expand the technological capabilities of hydraulic presses. This is important when implementing technologies with more complex kinematics than for stamping processes that are usually used on hydraulic presses.

The developed state diagrams show that UDS allows the implementation of the specified working cycle, the required kinematics of the tool movement, and the force mode of deformation for a group of technological processes, which expands the capabilities of universal hydraulic presses.

The process of selecting the structures of UDS elements is formalized. Their selection is proposed to be based on the construction of a taxonomy of constructive solutions for the connections of block and press elements. For information support of the project at the conceptual level, an expert assessment of constructive options for connections between UDS elements is used. Permissible types of connections between UDS elements are presented in the form of an adjacency matrix.

The design of the developed UDS for different work options is presented, and the design solutions are justified. The use of additional supports and locking mechanisms for temporary limitation of the mutual movement of the block elements allows the use of the working and lower cylinders to perform various technological operations. This approach provides a more complex sequence of technological operations for manufacturing complex parts. An example of using the developed die design for the SPD process using the RS method and various options for pushing parts out during stamping is presented. Thus, the design methodology is presented, and an example of expanding the technological capabilities of universal hydraulic presses due to the adopted design solutions is shown.

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Системне проєктування й розробка універсального штампового блоку для гідравлічного преса

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Мета. Удосконалення конструкції універсального штампового блоку (УШБ) для гідравлічного преса на основі системної інженерії та морфологічного синтезу технічних рішень.

Методика. При розробці універсального штампового блоку використані методи системної інженерії. Такий підхід дозволив сформулювати вимоги й вибрати якісні технічні рішення. Виділені й реалізовані етапи аналізу та покрокового проєктування вузлів. Виконана класифікація типів з'єднань елементів конструкції УШБ. Для опису зв'язків між елементами УШБ побудовані матриці суміжності. Це дало можливість формалізувати допустимі комбінації конструкції вузлів. Етапи роботи конструкції визначені з використанням діаграми станів для технологічного процеса штампування. Розглянуті й наведені різні варіанти циклу роботи преса з різними способами виштовхування поковок із матриці.

Результати. Розроблено набір підсистем для УШБ з урахуванням розширення технологічних можливостей гідравлічних пресів при реалізації технологій із більш складною кінематикою, ніж для процесів штампування, що зазвичай використовуються на гідравлічних пресах. Формалізовано процес вибору елементів УШБ. Показане розширення технологічних можливостей універсальних гідравлічних пресів за рахунок прийнятих конструктивних рішень.

Наукова новизна. Удосконалена конструкція універсального штампового блоку гідравлічних пресів на основі застосування методів системної інженерії. Розширення технологічних можливостей гідропресів здійснювалося на основі запропонованої класифікації типів з'єднань елементів конструкції УШБ і преса. Для вибору зв'язків між елементами конструкції УШБ розроблені матриці допустимих комбінацій з'єднань елементів. Розроблені діаграми станів для різних варіантів реалізації технологічних процесів.

Практична значимість. Розроблена методика застосування методів системної інженерії стосовно проєктування універсального штампового блоку для гідравлічних пресів. Показано, що застосування методів системної інженерії дозволяє гарантовано покращити їх технологічні можливості. На основі цього підходу розроблена конструкція УШБ для різних варіантів роботи. Застосування додаткових механізмів фіксації для тимчасового обмеження взаємного переміщення елементів блоку і преса дозволяє використовувати робочий циліндр і нижній циліндр гідропреса для виконання різних технологічних операцій. Такий підхід забезпечує більш складну послідовність технологічних операцій виготовлення деталей. Наведено приклад застосування розробленої конструкції УШБ для процесу інтенсивної пластичної деформації методом реверсивного зсуву.

Ключові слова: *системна інженерія, універсальний штамповий блок, система «прес-штамп»*

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