KAZAN FEDERAL UNIVERSITY

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AUTOMATED SYSTEM OF MODELING AND CONTROL OF THE TECHNOLOGICAL PROCESS OF ASSEMBLING UNRELEASABLE DETAILS BY PLASTIC DEFORMATION

Specialization 05.13.06 – Automated Control Systems of Technological Processes and Manufactures (in mechanical engineering)

ABSTRACT OF THESIS

(prepared by Candidate of Engineering Sciences)

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Scientific secretary of
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GENERAL CHARACTERISTICS

Actuality of the work. Currently, the development and implementation of automated process control systems with elements of artificial intelligence makes it possible to solve the problem of production implementation of complex tasks of manufacturing engineering products to ensure the required quality. Examples of such technologies are the processes of assembling all-in-one products. The main advantage of the use of all-in-one products is the ability to combine the properties of different steel grades in one single product. For example, with the use of such products it is possible to solve the problem of saving expensive alloy steels while maintaining the performance properties of the die tool.

Among the known methods of Assembly of all-in-one products, a special place is occupied by methods carried out using plastic deformation, when an all-in-one joint is obtained at a temperature below the melting temperature of the metals to be joined. At the same time, there are practically no zones of structural and chemical heterogeneity in the area of the compound, inherent in the methods of obtaining permanent products by melting welding.

The main problem of the Assembly of plastic deformation is to ensure the accuracy of the geometric dimensions and the strength of the connection elements of all-in-one products. The creation and implementation of automated process control systems contributes to the high quality of Assembly of all-in-one plastic deformation products.

The work is based on the achievements in the field of obtaining permanent joints by plastic deformation: S. B. Aynbindera, N. F. Kazakova, E. S. Karakozov, A. G. Kobelev, Yu. l. Krasulin, A. V. Meretskogo and I. V. Abramov, simulation and control of technological processes, including with application of methods of artificial intelligence: V. Shuvaeva G., Lvova N.. Gladkov E. A., L. A. Zadeh, E. N. Mamdani, Tsukamoto, N. G. Yarushkina, Sugeno, Yu. N. Hizhnyakova, Z. I. Batyrshina, V. N. Bondarev, etc.

To date, the lack of knowledge of the issues of creating automated control systems of technological processes of Assembly of all-in-one plastic deformation products, the lack of methods for accurate calculation of the parameters of the connected elements of the product, mathematical models of accounting for their form change in the Assembly process, due to the gradual localization of deformation in the connected elements of the product, makes process control in real time using existing automated systems almost impossible. In this regard, it is urgent to develop a system for modeling and controlling the automated technological process of Assembly of all-in-one products by plastic deformation, which will ensure the accuracy of the geometric dimensions and the strength of the connection of the elements of all-in-one products.

The object of research is the system of automated control of the technological process of Assembly of plastic deformation of permanent products.

The subject of research is the process of automated control of the Assembly of all-in-one plastic deformation products.

The goal of the work is to develop a system of modeling and control of the automated technological process of Assembly of all-in-one plastic deformation products with the required geometric accuracy and strength.

To achieve the goal, the following **scientific tasks** were set and solved:

1. To investigate the process of Assembly of all-in-one products by plastic deformation, to analyze the current state of control of this process.

2. Development of structural solutions to create a multi-level system of modeling and control of the automated technological process of Assembly of all-in-one plastic deformation products.

3. Development of mathematical models and algorithm for calculating the parameters of the technological process of Assembly of the connected elements of the product.

4. Development of a method for controlling the technological process of Assembly of an all-in-one product by plastic deformation.

Scientific novelty of the work:

1. The multilevel structure of the system of modeling and control in real time automated technological process of Assembly of all-in-one products by plastic deformation, characterized in that, taking into account the results of modeling the plastic flow of the metal, the gradual localization of deformations in the connected elements of the product is provided (*paragraph 3 of the specialty passport*).

2. Mathematical models, algorithm of calculation of geometrical parameters of the connected elements and parameters of technological process of Assembly of an all-in-one product displaying conditions of their plastic form change in real time are developed (*paragraph 4 of the passport of specialty*).

3. A method of real-time control of the process with the use of fuzzy logic for the correction of time parameters in order to improve the efficiency of production (*paragraph 1 of the passport specialty*).

Practical value of the work. The developed automated system is used for the production of a pilot batch of composite tools in NPA "Technopark-at" (Ufa) and is recommended for implementation in production. A program for calculating the geometric parameters of the workpieces of an all-in-one product manufactured by plastic deformation has been developed (protected by the certificate of state registration of the computer program No. 2017614544). Results of work are used in educational process at realization of the program of the magistracy in the direction of preparation 15.04.04 "automation of technological processes and productions" at Naberezhnye Chelny Institute (branch) of KFU.

Method of research. Methods of object-oriented design of information systems, algorithmization, plasticity theory, mathematical and simulation modeling, as well as methods of building systems using artificial intelligence were used to solve the problems..

Presentation of the work. The results of the work were reported and discussed at the following international conferences: International scientific and practical conference "Information technologies. Automation. Actualization and solution of problems of training of highly qualified personnel (ITAP-2014)" (Naberezhnye Chelny, 2014); International school-conference of students, postgraduates and young scientists "materials and technologies of the XXI century" (Kazan, 2016); International scientific and technical conference " Innovative engineering technologies, equipment and materials – 2016 "(Kazan, 2016); International scientific and technical conference " Informatics and technologies. Innovative technologies in industry and Informatics"; Moscow technological University, Institute of physics and Technology (Moscow, 2017); International scientific and technical conference " Innovative engineering technologies, equipment and materials – 2017 "(Kazan, 2017).

Publications. On the subject of the thesis the author published 12 works, including 5 articles in publications recommended by the VAK, 3 articles indexed in Scopus and 1 certificate of state registration of computer programs.

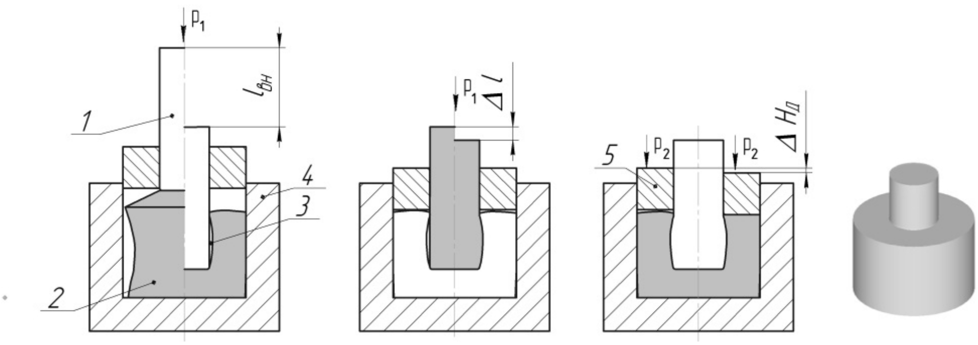
Structure of the manuscript. The thesis consists of an introduction, four chapters, conclusion, list of references, including 111 titles, and one Annex. The work is presented on 131 pages of typewritten text containing 8 tables, 56 figures.

CONTENTS

The introduction highlights the relevance of the theme of the thesis, the purpose and objectives of the study, the novelty and practical significance of the results.

The first Chapter provides a brief overview of the existing automated modeling and control systems, investigated the possibility of creating an automated process for obtaining permanent joints of plastic deformation. A brief overview of the existing methods of manufacturing of all-in-one metal products is given. According to the results of the patent information review, a method for manufacturing all-in-one products by plastic deformation is proposed, based on one characteristic feature of the cylindrical workpiece forming during the open piercing operation: at the values of the punch diameter d in the range of 0.3÷0.7 from the initial diameter of the workpiece D_0, during the deformation, an annular gap between the piercing and the cavity walls is formed. This feature can be used both in the manufacture of all-in-one metal products, and in the technology of recovery of plastic deformation of worn surfaces of parts, with a barrel shape of the surfaces to be connected.

Figure 1 shows the technological scheme of the proposed method of Assembly of axisymmetric all-in-one metal products with a barrel shape of the surfaces to be connected, consisting of four successive stages. As the connected elements of the all-in-one product are the shaped billet 2 and the rod 1 introduced into it.



a) b) c) d)

Figure 1. Diagram of the method of Assembly of all-in-one products

Note: in the figure, the deformable object is marked in gray at the appropriate stage

In the first stage, "the introduction of the web" in the heated to the forging temperature of the shaped workpiece 2 on the depth $l_{вн}$ implement terminal 1 in the matrix 4 (Fig. 1, a). At the second stage, the "Exposure" compound is kept for a time $\tau_{кр}$ for heating the embedded part of the rod in order to reduce the yield strength of its material. After that, at the third stage, the "rod Landing" is carried out the landing of the embedded part of the rod by the amount of Δl, due to which the filling of the annular gap 3 by the rod material occurs (Fig. 1, b). And in the fourth stage of the "Final Assembly" produce the final Assembly of the ring tool 5 na $\Delta H_{д}$. (Fig. 1, b). Figure 1 (d) shows a 3D model of the assembled elements.

The forming of the blank according to the scheme of open firmware with the formation of an annular gap is provided by its shaped shape, taking into account the unevenness of deformation. In addition, this form of procurement allows to obtain the lateral surface closest to the cylindrical and end surfaces is compensation of utiny (Fig. 1, a).

This technology of production of all-in-one products by means of Assembly of their plastic deformation is based on combination of processes of processing of metals by pressure and welding by pressure. The main problem of the Assembly process is to ensure the geometric accuracy and strength of the all-in-one product. The most effective, and often the only solution to this problem is the development and implementation of automated control systems. The most interesting are adaptive control systems using the approaches of indirect assessment of controlled indicators. With the help of these systems, it was possible to significantly improve the efficiency of production of all-in-one products of ultrasonic, contact, diffusion and other types of welding, as well as the production of billets by metal forming due to adaptive control of press equipment.

However, the existing automated systems and approaches to the management of the considered group of technological processes are not applicable or require significant improvement due to the following features:

- the need to take into account the shaping of the shaped billet in the Assembly process;
- in the process of Assembly there is a gradual change of the object of deformation;
- no possibility of direct measurement of the temperature in the connection zone, which determines the geometric accuracy and strength of the all-in-one product;
- unsteadiness of temperature and power conditions.

Thus, it is necessary to create a system for modeling and controlling the automated technological process of Assembly of all-in-one plastic deformation products with the required geometric accuracy and strength, taking into account the above features. To achieve this goal, it is necessary to solve the tasks set in the thesis.

In the second Chapter the structure of multilevel automated system of modeling and control of technological process of Assembly of all-in-one products by plastic deformation aimed at the automated preparation of technological process and management of process of Assembly of a product in real time is offered (Fig. 2).

The initial data of the developed system are the final dimensions of the all-in-one product after Assembly and data on the properties of the materials of the connected elements of the product.

The structure of the system includes the block " Automated system of technological preparation of production "(ASTPP) and the block" Automated process control system " (ACS TP).

Block design-consists of the following modules:

- Module analysis of manufacturability: solves the problem of the applicability of the technology on the geometric parameters and check for compatibility of the strength properties of the connected elements of an all-in-one metal product;

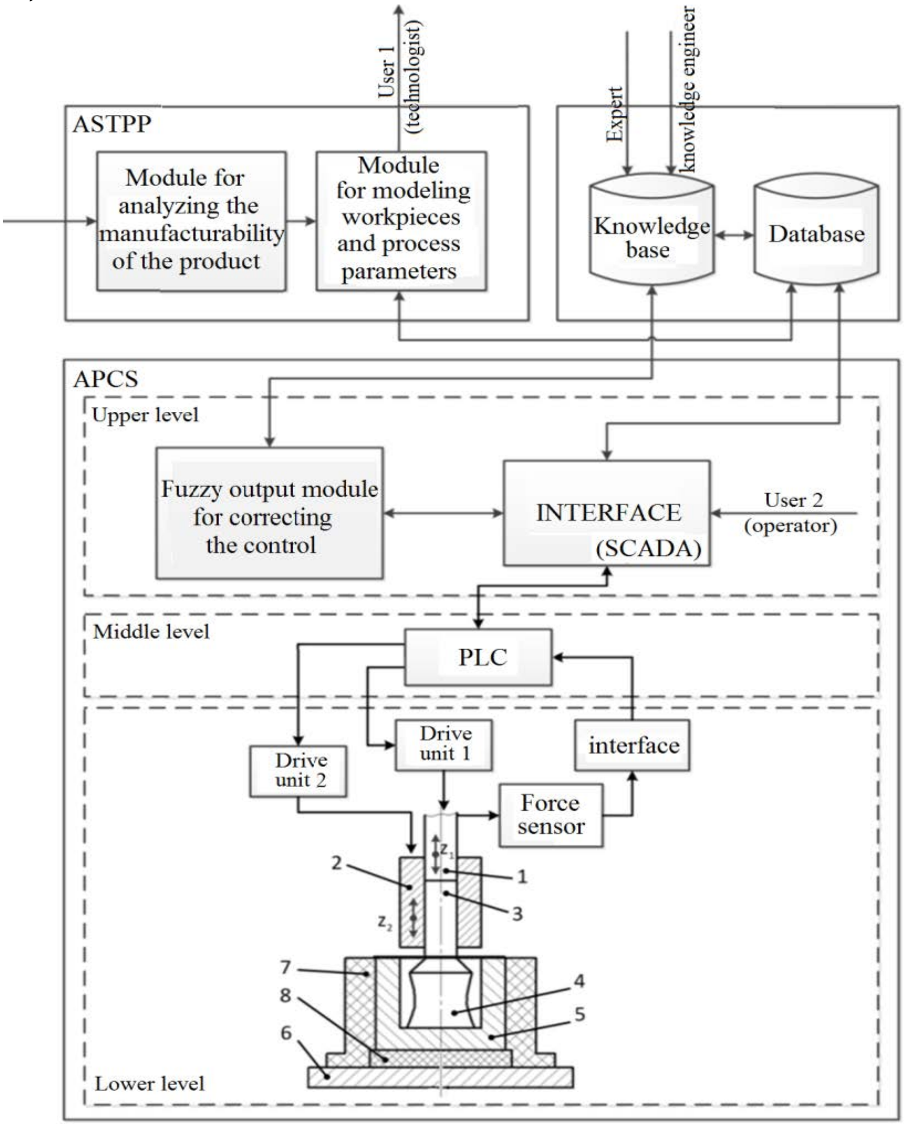


Figure 2. Structure of the automated system of modeling and control of Assembly of all-in-one products by plastic deformation:

1-rod; 2-clip; 3-rod; 4-shaped blank; 5-matrix; 6 - bottom plate; 7 - heat - insulating casing; 8-heat-insulating gasket.

- A module for simulation of the workpiece and the process parameters: calculates the dimensions of the shaped workpiece and the rod, determines the parameters of the process; forms the input to block APCS. The module is based on the method of selection of geometric parameters of the shaped workpiece.

Figure 3 shows the basic geometric parameters of the process of open flashing cylindrical workpiece height H_0 and diameter D_0 (contour 1) cylindrical punch diameter d with a taper angle of the end α. The result of the deformation the workpiece is precipitated to a height of $H_к$, and the side surface of the workpiece acquires the shape of a barrel, characterized by the diameter $D_б$.

A characteristic feature of the workpiece forming with open firmware is the formation of a closed annular gap (marked in figure 3 in gray), the volume of which can be characterized by the following relative value:

$$\theta_з = \frac{V_з}{V_{в.п.}} 100\%, \quad (1)$$

where $V_з$ - the volume of the annular gap, mm^3; $V_{в.п.}$ – the volume of the embedded part of the cylindrical punch, mm^3.

In addition, the flashing process always accompanied by the formation on the end face of the workpiece from the introduction of the punch of utiny, which can be quantitatively described by the angle φ.

To accurately determine the displacement of the workpiece metal when open firmware to determine the final shape of the workpiece values $D_б$ and $H_к$ is not enough. In this regard, on the side surface of the workpiece we denote the equidistant points i and introduce the vector $\vec{s}_i\left(\frac{\Delta D_i}{2}, \Delta H_i\right)$ of the movement of i–points from their initial position 1, 2,...n to the finite 1*, 2*,...n*. Components $\frac{\Delta D_i}{2}$ and ΔH_i is the magnitude of the displacement of the i–points in the radial and axial directions, respectively.

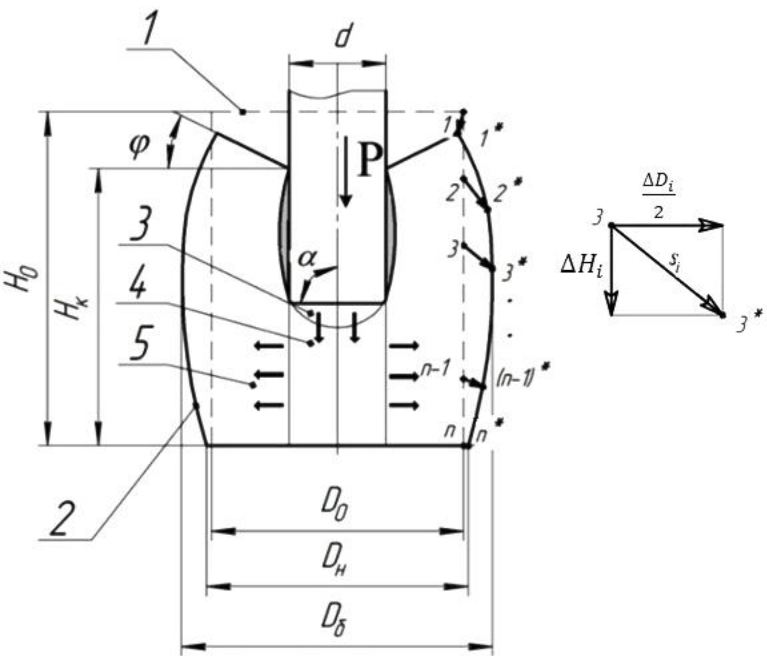


Figure 3. Analysis of the deformation of the cylindrical workpiece when the open firmware

By postponing the data movement points from the contour of the desired shape of the sample, you can get the contour shaped workpiece. The resulting circuit should be adjusted to the angle φ from the education of utiny. To do this, through a point with a coordinate $(\frac{d}{2}; H_0)$, the secant plane is carried out at an angle φ to the end surface.

To calculate the geometric parameters of the shaped workpiece and rod size all-in-one product after Assembly it is necessary to develop a mathematical model that relates the parameters of a finite deformation of the workpiece ΔD_i, ΔH_i, $\Delta D_б$, $\Delta H_к$, φ, $\theta_з$ with the following variable parameters of the geometric dimensions prior to deformation: d/D_0 is the relative diameter of the rod; H_0/D_0 the relative height of the workpiece; α - the angle of the base of the stem.

For the development of universal mathematical models of the parameters ΔD_i, ΔH_i, $D_б$ and $H_к$ of forming the workpiece during the introduction of the rod to get away from the absolute values, it is proposed to use their relative values:

$$\Delta D_i^* = \frac{D_i - D_0}{D_0} \cdot 100\% \,, \quad (2)$$

$$\Delta H_i^* = \frac{H_i - H_{i_0}}{H_{i_0}} \cdot 100\% \,, \quad (3)$$

$$\Delta D_б^* = \frac{D_б - D_0}{D_0} \cdot 100\% \,, \quad (4)$$

$$\Delta H_k^* = \frac{H_k - H_0}{H_0} \cdot 100\% \,. \quad (5)$$

Thus, it is necessary to develop the following set of mathematical models:

$$\Delta D_i^* = f_1(d/D_0;\ H_0/D_0; \alpha), \quad (6)$$

$$\Delta H_i^* = f_2(d/D_0;\ H_0/D_0; \alpha), \quad (7)$$

$$\Delta D_б^* = f_3(d/D_0;\ H_0/D_0; \alpha), \quad (8)$$

$$\Delta H_k^* = f_4(d/D_0;\ H_0/D_0; \alpha), \quad (9)$$

$$\varphi = f_5(d/D_0;\ H_0/D_0; \alpha), \quad (10)$$

$$\theta_з = f_6(d/D_0;\ H_0/D_0; \alpha). \quad (11)$$

Figure 4 presents the developed algorithm of calculation of the dimensions of the mating elements as well as the required displacement of the tool during the Assembly drawing ready all-in-one metal products with the use of the above mathematical models.

After entering the initial data using the formulas (4), (5) and the system of equations from (8), (9), (11) the diameter D_0 and height H_0 of the cylindrical billet, values α and $l_{вн.}$. In the calculation, it is assumed conditions that the desired contour of the cylindrical workpiece after the firmware fits the contour of the finished permanent product. This condition is expressed by the following system of relations:

$$\begin{cases} d = d_{гот} \\ H_к = k_V \cdot H_{гот} \\ D_б = D_{гот} \end{cases} \quad (12)$$

where$H_{гот}$ and $D_{гот}$ – the height and diameter of the housing part of the all-in-one product after Assembly; $d_{гот}$ – diameter shaft portion integral of the product after Assembly; $H_к$ and $D_б$ – size cylindrical workpiece after the implementation of pin; k_V – correction factor for volume (on the first cycle of the calculation algorithm k_V=1).

Due to the fact that there are a lot of such contours, the contour with the maximum possible relative value of the annular gap volume is selected $\theta_з = \theta_{з\,max}$.

Substitution of the obtained values in (6), (7) and (10) and with the help of formulas (2) and (3) calculates the values of displacement of the lateral surface points in the radial $\frac{\Delta D_i}{2}$ and axial ΔH_i directions, as well as the value of the angle of the top end surface φ. The obtained values are used in the construction of the contour shaped workpiece.

The length of the embedded part of the rod $l_{вн}$ is adjusted. by the amount$\Delta l = \frac{\theta_з}{100\%} \cdot l_{вн}$.

Then the actual value of the correction factor is calculated $k_V^{факт}$:

$k_V^{факт} = \frac{V_{гот}}{V_ф + V_{ст}}$,

where $V_{гот}$, $V_ф$ and $V_{ст}$ – volumes of the finished product, shaped billet and rod, respectively.

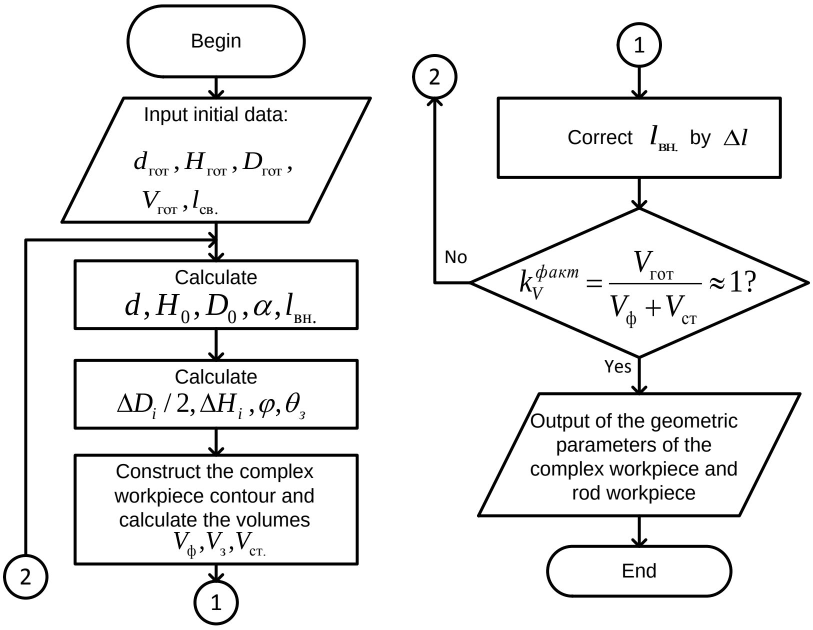


Figure 4. Algorithm for calculation of geometrical parameters of shaped billet and rod

The calculation with the output of the design results is stopped at the values $k_V^{факт} \approx 1$ with a deviation within ±0,01, corresponding to the range of values for accurate hot stamping. In case of large deviations, the calculation starts again before the condition (13) is met, but with the value $k_V = k_V^{факт}$ in (12).

Block APCS built on a three-level principle and contains the lower, middle and upper levels.

At the lower level, the sensor signals are coordinated with the inputs of the control device, as well as the generated commands with the actuators. At the Middle level of the PLC (Programmable Logic Controller) on the basis of data on the status of the controlled parameters gives control signals to the actuators. The top level is an intelligent add-in in the form of a fuzzy inference module that corrects the Assembly process control based on fuzzy rules depending on the data received from the lower level sensors.

The third Chapter is devoted to the development of mathematical models (6) - (11), reflecting the conditions of plastic forming shaped workpiece with open firmware in real time.

With the help of simulation in the software complex Deform-2D studies of the cylindrical shape of the open firmware for different ratios of the geometric dimensions of the workpiece and the rod, as well as the shape of the end of the rod. Accepted values of variable factors: relative diameter of the rod d/D_0 = 0.3÷0.7;

relative height of the workpiece H_0/D_0= 0.5÷1.5. (for large values H_0/D_0 difficult to ensure the stability of the rod); angle at the base of the punch α =45°÷90°. The depth of the punch insertion is 0, $8H_0$ (a large depth of the firmware leads to the formation of a removable jumper and is used mainly for piercing the through hole in the workpiece).

As a result of data processing:

1. The values of the minimum value of the coefficient of friction μ_{min}, in which the open firmware punches with relative diameters $d/D_0$0=0,3÷0,7 accompanied by the formation of a closed annular gap.

2. It is established that the maximum values of $\theta_з$ are observed when introducing a rod with a taper angle α = 90° for all different combinations d/D_0 and H_0/D_0 (Fig. 3).

3. The developed mathematical model $\theta_з$, ΔD_i^*, ΔH_i^*, $\Delta D_б^*$, ΔH_k^* and φ from the relative stem diameter d/D_0, the relative height of the workpiece H_0/D_0, allowing the simulation of the process of forming in open firmware for the calculation of the shaped workpiece and rod size all-in-one product after Assembly in the automated mode.

4. Range is set to relative sizes $d_{гот}/D_{гот}$ all-in-one products, whose manufacture is possible by using the proposed technology, which is $d_{гот}/D_{гот} \epsilon [0,27; 0,47]$. The magnitude of $H_{гот}/D_{гот}$ of products obtained is in the range [0,4;1,24].

The fourth Chapter is devoted to the algorithmization of control with elements of artificial intelligence technological process of Assembly of all-in-one plastic deformation products. As a result of the research, a method of real-time control using fuzzy logic was developed.

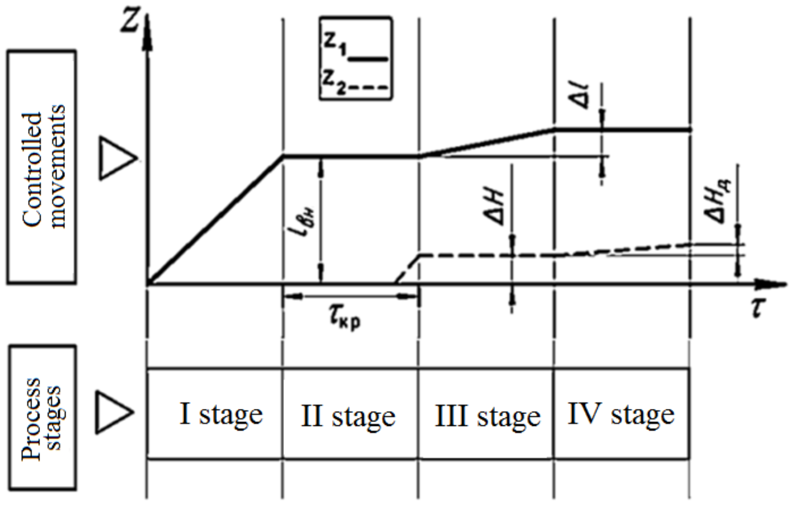


Figure 5 - Example of an all-in-one Assembly cycle

The main task of the algorithm is to control the movements z_1 and z_2 of the press rod 1 and the drive of the cage 2, respectively (see Fig. 2), the holding time of the connection $\tau_{кр}$ in four successive stages (Fig. 5).

At the first stage of the Assembly process, the system moves the press rod by $z_1 = l_{вн}$. After the introduction of the rod system calculates the value $\tau_{кр}$, and in the second stage the connection is maintained during this time. At the third stage, the press rod is moved by the value $z_1 = \Delta l$. The values of $l_{вн}$ and Δl are calculated in the ASTP block and stored in the database. In the fourth stage, the first is the supply of the clip by moving the clip z_2=ΔH. Then the final Assembly of the connection is carried out by moving the clip $z_2 = \Delta H_д$ according to the rule: If the force *P>0*, then the "stop drive of the clip". The source of the force information is the force sensor. Managing a full cycle of the Assembly is done using a PLC.

The absence of the possibility of direct measurement of the temperature of the shaped workpiece and the rod in the connection zone at the second stage of Assembly in real time and the presence of many random production factors eliminates the use of traditional methods of automation. In this regard, to determine the $\tau_{кр}$ in the system provides a fuzzy output module for control correction depending on the actual conditions of the process of Assembly of an all-in-one product.

In fuzzy inference systems, the basic concept is a linguistic variable consisting of five objects:

$$<X, U, T(x), G, S>, \quad (14)$$

where *X* is the variable name; *U* is the universal set; *T(x)* is the fuzzy labels; *G* and *S* are syntactic and semantic rules respectively.

As *X*, the following parameters of the Assembly process of an all-in-one product are set, namely: the diameter of the body element of the product $D_{гот}$, the ratio of the diameter of the rod to the diameter of the body element of the product $d_{гот}/D_{гот}$ after Assembly, the ratio of the diameter of the body element of the product height to build H_0/D_0, the unit deformation force on the scheme an open firmware shaped workpiece *p*, the holding time of the connection $\tau_{кр}$.

Universal set *U*-range of possible values of *X*, depending on the characteristics of the control object: $D_{гот}$ from 20 to 40 mm; $H_{гот}/D_{гот}$ from 0.25 to 0.5; H_0/D_0 from 1.0 to 1.5; *p* from p_{min} to p_{max} MPa, $\tau_{кр}$ from $\tau_{кр\cdot min}$ to $\tau_{кр\cdot max}$ sec. The values of *p*, $\tau_{кр}$ and their ranges depend on the rheological and thermophysical properties of the materials of the connected elements of an all-in-one product.

Joint consideration of linguistic variables $D_{гот}$, $d_{гот}/D_{гот}$, H_0/D_0, *p*, $\tau_{кр}$ are best described by triangular membership functions (trimf).

For finding the values of linguistic variables *p*, $\tau_{кр}$ at the boundaries of the temperature interval of deformation of the material of the shaped blanks for different combinations of variables $D_{гот}$, $d_{гот}/D_{гот}$, H_0/D_0 was carried out an experimental study of the build all-in-one products for example items: rod of X12M, shaped billet of steel U10A, the lower limit of the temperature interval of deformation -1000^{0}C, top - 1200^{0}C.

Fuzzy control rules are formed on the basis of the resulting linguistic variables. These rules have the following form:

IF $D_{гот}$ AND $d_{гот}/D_{гот}$ AND H_0/D_0 AND *p* THEN $\tau_{кр}$.

On the basis of the obtained fuzzy rules, the second level of the knowledge base is formed, which has the following form:

IF 20 AND 0,25 AND 1,0 AND 247 THEN 16;

IF 20 AND 0,375 AND 1,0 AND 216 THEN 11,5;

………………………………….

IF 40 AND 0,5 AND 1,5 AND 138 THEN 58.

Using this knowledge base you can get fuzzy control values. Using these values, we perform a defuzzification process. Under diversification is a process of conversion of fuzzy values obtained in fuzzy inference, in the clear, which can be used to control the shutter speed of the connection. Mamdani algorithm is used for defuzzification.

To verify the adequacy of the control model, the experimental and data values $\tau_{кр}$ obtained as a result of fuzzy inference are compared, and the value of the mean square error for a series of 8 experiments is calculated. The mean square error was 2.74%, which provides the necessary accuracy in the control of the Assembly process in real conditions.

Were used to test the obtained results for manufacturing technology composite tool for punching holes, which is a one-piece product made of steel X12M (stem) and U10A (shaped preform) with $d_{гот}$ = 12 mm; $D_{гот}$ = 31 mm; $H_{гот}$ = 21 mm; $l_{св}$ = 15mm.

According to the results of mechanical tests of samples tensile strength $\sigma_в$ all-in-one connection was 241-265 MPa per unit area of the contact surface of the connected elements of the product. The analysis of the geometric accuracy of the obtained all-in-one product, as a result of which the deviation in weight of the product is equal to 7.57%. Thus, an all-in-one product with a deviation of geometric parameters within the tolerances of accurate hot forging, which is equal to 5-25% by weight (volume) of forging, is obtained.

MAIN RESULTS

The main result of the dissertation work is the solution of the scientific problem, which has an important economic value, which is to ensure the geometric accuracy and strength of all-in-one products manufactured by assembling plastic deformation, by automating their production and intellectual support of management processes.

The following scientific and practical results were obtained during the research on the subject of the thesis:

1. The analysis of modern automated systems and approaches to control the Assembly of all-in-one plastic deformation products.

2. The multilevel structure of the system of modeling and control in real time automated technological process of Assembly of all-in-one products by plastic deformation, characterized in that, taking into account the results of modeling the plastic flow of the metal, the gradual localization of deformations in the connected elements of the product is provided.

3. Mathematical models, algorithm of calculation of geometrical parameters of the connected elements and parameters of technological process of Assembly of an all-in-one product displaying conditions of their plastic forming in real time are developed.

4. A method of real-time control of the process with the use of fuzzy logic for the correction of time parameters in order to improve production efficiency. The control effect on the duration of the second stage is formed on the basis of the results of fuzzy logic depending on the geometric parameters of the product and the deformation force at the first stage.

5. Approbation of the obtained results on the example of the manufacture of workpieces of the punch for punching, which is a one-piece metal product from steel X12M (stem) and U10A (shaped preform) with the following geometrical parameters: dгот = 12 mm; $D_{гот}$ = 31 mm; $H_{гот}$ = 21 mm; $l_{св}$ = 15mm. The analysis of the geometric accuracy of the obtained all-in-one product, in which the obtained deviation value for the mass (volume) integral is equal to the product of 7.57%, which corresponds to the exact tolerances of the die forging (5-25%). As a result of mechanical testing of 5 samples, the values of the tensile strength $\sigma_в$ in the range of 241-265 MPa were obtained.

AUTHOR’S PUBLICATIONS

Scientific articles in journals recommended by the VAK:

1. Valiev A. M. the Management of technological process of assembling the product components metal products IOS. / Simonova L., Valiev A. M., Pankratov D. L., Sarvarov F. S. // Fundamental research. - 2014. - № 9 (8). – P. 1693-1696;

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