DESIGN OF ELECTROHYDROIMPULSE SHEET METAL FORMING USING LS-DYNA

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ABSTRACT

Stages of the transferring processes of electrical energy stored in the capacitor battery into the energy of plastic deformation were considered. Model of a discharge circuit with the variable part of resistance defined by electrical resistance of the discharge channel and model of formation and extension of plasma - vapour cavity during electric discharge in a liquid were presented. Using the example of manufacturing a part of complex geometry, the possibility of estimating pressure parameters in computer modelling of combined electrohydraulic sheet forming in the LS-DYNA complex is considered. An equivalent axisymmetric die model with the same volume and depth was constructed. Appearing of the pulsed and quasistatic nature of the workpiece deformation during the different stage of electrohydraulic discharge in large - volume chambers were carried out. The developed computer model of multi-digit sheet forming made it possible to evaluate the pressure parameters and determine the required changes in the parameters of the technological process.

Keywords: electrohydraulic sheet forming, computer modelling, estimation of pressure parameters, discharge channel model, large - volume cambers.

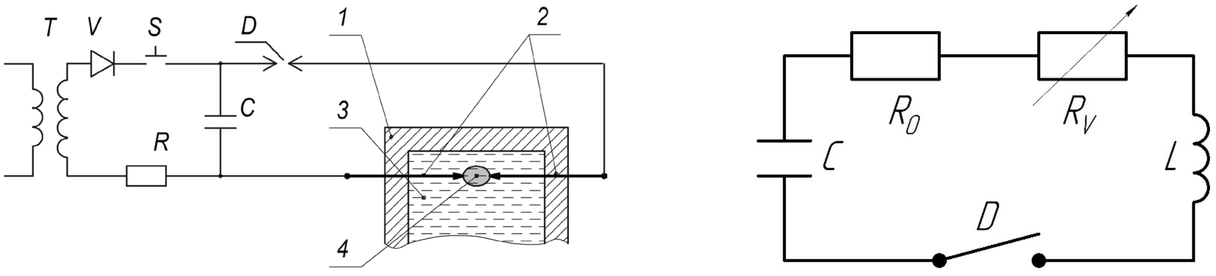
INTRODUCTION

Among the production technologies that use a high - voltage electrical discharge in a liquid the Electro - Hydraulic Forming (EHF) takes an important place. EHF is efficient in a batch and one - off production of complex shape parts out of metal blanks or tubes [1, 2]. In EHF there is only one rigid tool (the second one is a liquid) which reduces the cost of the tools. The pulse loading, high - rate metal deforming, and impact contact conditions provide better formability and reduced spring back in comparison with conventional forming [3]. These factors become more crucial when forming especially thin blanks (less than 0.4 - 0.5 mm).

The industrial implementation of electrical discharges in liquids started in 60th of 20th century and was accompanied by research of the process physics. The experimental research of electrical and mechanical processes, defining EHF, by V.N. Chachin, E.V. Krivitskiy and others created a foundation for further theoretical modelling of the technology [4, 5].

The scheme of electrohydraulic - impulse loading is presented below (Fig. 1a). The capacitor battery *C* of electro - impulse unit is charging up to some ten's kV from step - up transformer T and high - voltage rectifier V, R. When battery discharges through controlled discharger D the electrical breakdown of interelectrode gap of electrode system 1 in liquid 3 in discharge chamber occurs. Next explosive expansion of plasma gas cavity due to adiabatic heat by impulse current occurs, that leads to compression in a liquid. Impulse pressure acts on deformable sheet metal piece and performs the required forming operation.

Discharge in a liquid occurs as a heat breakdown. By



a) b)

Fig. 1. (a) scheme of electrohydraulic - impulse loading: 1 - discharge chamber, 2 - electrode system, 3 - liquid, 4 - plasma gas cavity; (b) scheme of electrical circuit at high - voltage discharge in a liquid.

such conditions the physical processes of transferring of electrical energy stored in the capacitor battery into the energy of plastic deformation have some stages:

1. Prebreak down stage, electrical breakdown in a liquid and forming of discharge channel. After giving the high voltage on electrodes 2 in a liquid 3 in the interelectrode gap the distortion of field is arising that leads to intensive heating of a liquid and local temperature increasing. Intensive energy releasing leads to decreasing of electrical conductance and evolution of instability process. The area of liquid comes to boil and gas - vapor cavity 4 is formed. If given voltage is enough, then in formed gas gap the electrical breakdown arises.

2. Stage of transforming and releasing of energy in discharge channel. From the breakdown moment via the interelectrode gap, that is a low - temperature high - pressure plasma, the discharge of capacitor battery started (Fig. 1b). Here R_0 - parasitic resistance of discharge circuit, R_V - resistance of discharge channel, L - inductance of discharge channel. In this work we don't consider low - temperature plasma in a gas - vapor cavity as an object of simulation. Instead, we just define some resistance law of a plasma channel.

Computer modelling greatly facilitates debugging and research of any new technologies [6 - 8].

The goal of the work was to develop a computer model of combined electrohydroimpulse forming of sheet metal using the finite elements complex LS-DYNA.

EXPERIMENTAL

Model of a discharge circuit with the variable part of resistance defined by electrical resistance of the discharge channel and model of formation and extension of plasma-vapour cavity during electric discharge in a liquid are presented below. The variant of a thermal breakdown in the interelectrode gap in a liquid without an initiating wire is considered. Such a discharge is typical for discharge chambers in the industrial units for an EHF and can be used for practical calculations.

Differential equation for current i(t) in a circuit (Fig. 1) with varying resistance of discharge channel R_V, with summary own resistance of electro - impulse unit and contacts R_0, and inductance of discharge circuit L is given by

$$\frac{d^2 i}{dt^2} + \frac{R_V(i,t) + R_0}{L} \cdot \frac{di}{dt} + \frac{1}{LC} i = 0, \quad (1)$$

with follows initial conditions

$$i(0) = 0, \left.\frac{di}{dt}\right|_{t=0} = -\frac{U_0}{L} \quad (2)$$

where U_0 - initial voltage of capacitor battery. The law $R_V(i, t)$ is given for conditions of thermal breakdown [5]. Solving the problem numerically (1, 2) with considering the values i and R_V we have a law of electrical energy liberation in a discharge channel E(t).

$$E = \int_0^t i^2(t) R_V(i,t) dt. \quad (3)$$

For the computer calculations it is reasonable to use following formula for the electrical power low N(t):

$$N = i^2 R_V(i,t) \quad (4)$$

The computer program for calculating of resistance of the interelectrode gap and obtaining the functions E(t) and N(t), needed for the complete mathematical model of EHF, is developed. Considering the fact of varying of parameters of electro impulse units it is advisable to calibrate computer model basing on parameters of a given unit.

An example of such law and other parameters of a discharge process is presented on Fig. 5, 6. Dimensionless values of discharge current i/i_0, interelectrode voltage u/u_0, interelectrode resistance R/R_0, and energy released in interelectrode space E/E_0 all subject to dimensionless time t/T_0 are shown. Simulation was performed with follows parameters: $U_0 = 16$ kV, C = 100 mF, L = 0.8 mH, R = 0.02 W. Normalizing values are: $i_0 = 168.68$ kA, $R_0 = 0.09$ W, $T_0 = 60$ ms, $E_0 = 12.8$ kJ.

The dimensionless function of electrical energy release in the discharge channel is presented in Fig. 2.

The experimental research that was made in Peter the Great St. Petersburg Polytechnic University earlier have shown that a wave reflection in the discharge chambers of a large volume for the industrial EHF has no significant influence on the parameters of releasing of energy.

RESULTS AND DISCUSSION

Estimating of pressure parameters for EHF processes for forming of part from sheet metal were carried out in LS - DYNA. The typical formed automotive parts have size more than 0.5…1.0 m and complex geometry. As an example, were considered one of these parts that is presented by his forming die, adapted for EHF shown in Fig. 3. For forming the electro - impulse unit with parameters that give energy low shown in Fig. 4 is selected. Duration of energy releasing is T_0 at 50 ms.

The workpiece material is IF grade sheet metal 1 mm thick with the characteristics of the strain hardening curve:

$$\sigma_s = B \cdot \varepsilon^m, \qquad (5)$$

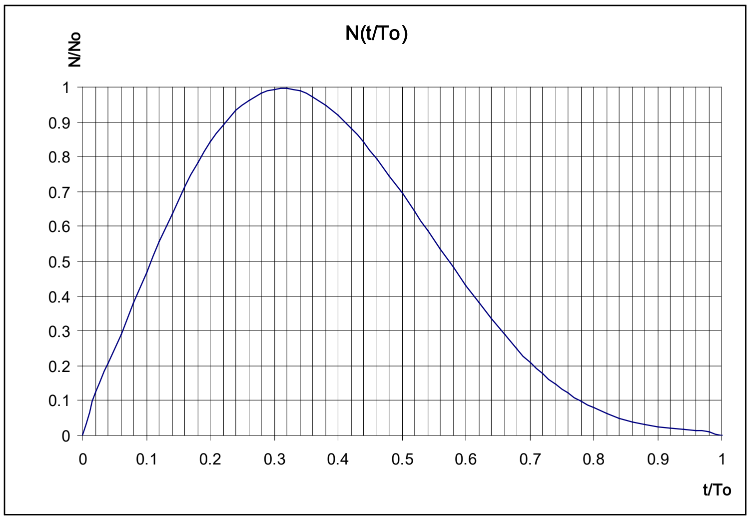


Fig. 2. Dimensionless function of electrical energy release in the discharge channel.

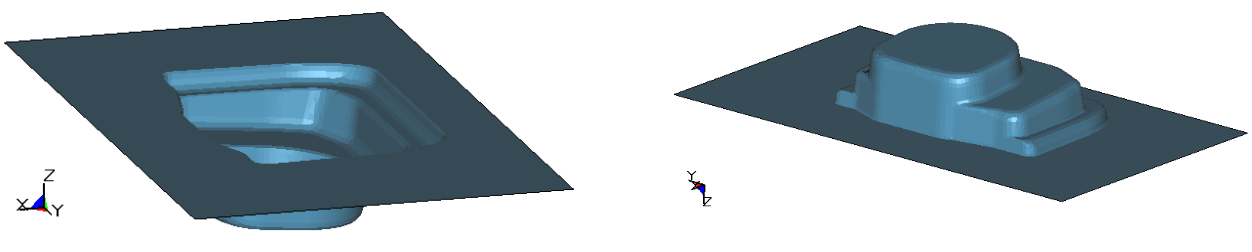
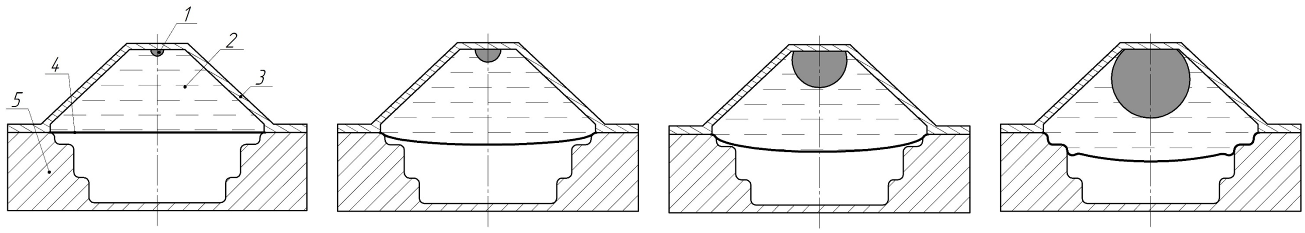


Fig. 3. Geometry of the stamped part.



a) b) c) d)

Fig. 4. Stages of part deformation: (a) time =0.001 s; (b) time = 0.005 s; (c) time =0.01 s; (d) time = 0.015 s; in the position (a) are shown: 1 - vapor cavity, 2 - liquid, 3 - discharge chamber, 4 - sheet workpiece, 5 - forming die.

where B at 554 MPa, m @ 0.227.

To carry out the calculation in an axisymmetric formulation, an equivalent axisymmetric model of the die was made, which has the same volume and depth as the die shown in Fig. 3. The calculation was carried out in a flat setting using the finite element complex LS - DYNA [9]. The biaxial deformation process was created by an appropriate holder force. Simulated a coaxial discharge (Fig. 4).

In this case, the process of multi - bit forming is simulated, when in several digits the workpiece is formed to the bottom of the die, and then the calibration process is carried out along the topography of the bottom of the die. In Fig. 4d, shows the result of the shape change after the first discharge. The total shaping time was 0.015 s. The duration of energy release in the discharge channel (T_0 at 50 μs) is significantly less than the total time of shape change.

The pulsed nature of the workpiece loading appears only at the beginning of the deformation process and subsequently at the calibration stage (Fig. 5a). When the shock wave reaches the surface of the workpiece, the workpiece is separated from the liquid (Fig. 5b). Next, the workpiece is deformed under the action of the hydraulic fluid flow almost quasi - statically. This explains some of the experimental effects of EHF. In particular, the pressure amplitude in a large - volume discharge chamber is determined by the dimensions of the chamber or the liquid volume [10]. The shape of the electrode system in a large - volume chamber will not have a significant impact on the nature of hydrodynamic phenomena but will primarily determine the efficiency of energy release in the discharge channel. In this case, at the initial stage of forming, a hydraulic fluid flow is predominantly created, due to which the main shape change of the workpiece is carried out [11].

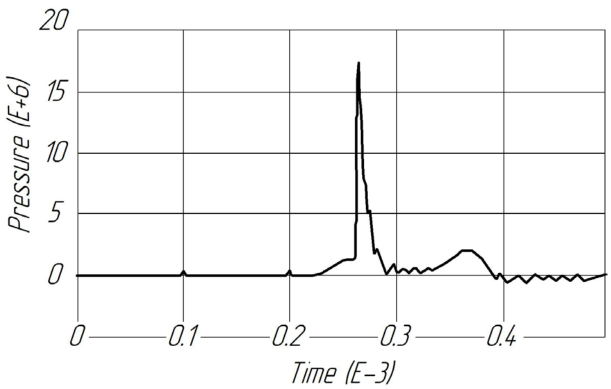
The quasistatic nature of the workpiece deforming process in large - volume cambers at the stage of preliminary filling of the die relief makes possible to significantly simplify the overall calculation of EHF processes.

An example of calculation of the IF metal workpiece deformation are given below. The die, workpiece and holder were modelled with shell elements (Fig. 6). The workpiece shape is optimized based on previous calculations.

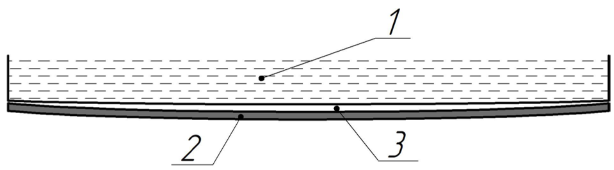
The blank, molded after three discharges, has the form shown in Fig. 7. Almost the entire flange part went to the center of the workpiece.

However, if we compare the deformation parameters with the limit deformation diagram (FLD), then, starting from approximately 0.015 s, the workpiece material is destroyed (the presence of a red area on Fig. 8f). Moreover, destruction occurs at the stage of free quasi - static molding, when the workpiece does not touch the bottom of the die.

By varying the shape of the workpiece, the holder force, changing the forming pattern or simplifying the shape of the die, it is possible to get a positive result in repeated computer simulations. An increase in the pressure impulse duration in 1.5 times and the amplitude pressure magnitude, as well as a decrease in blank holder force by 10 % and an increase in the part radius of curvature, led to the possibility of obtaining the part without risk of destruction.

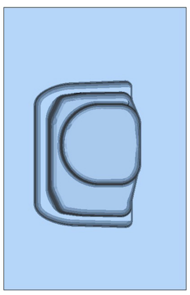


a)

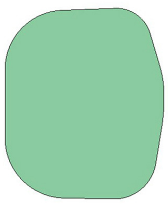


b)

Fig. 5. Pressure in the selected fluid element at the initial stage of loading the workpiece: (a) pressure - time curve; (b) workpiece separation from the liquid at time = 0.005 s: 1 - liquid; 2 - workpiece; 3 - air gap.



a)



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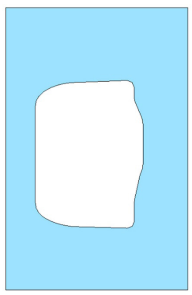


c)

Fig. 6. Geometric models: (a) die; (b) workpiece; (c) holder.

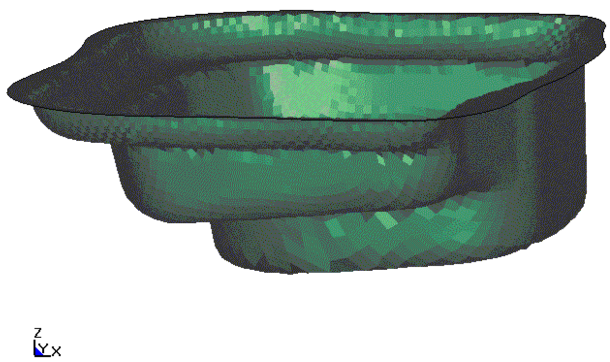
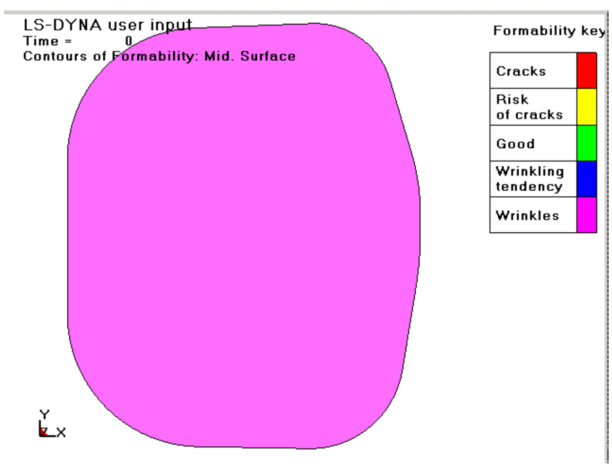
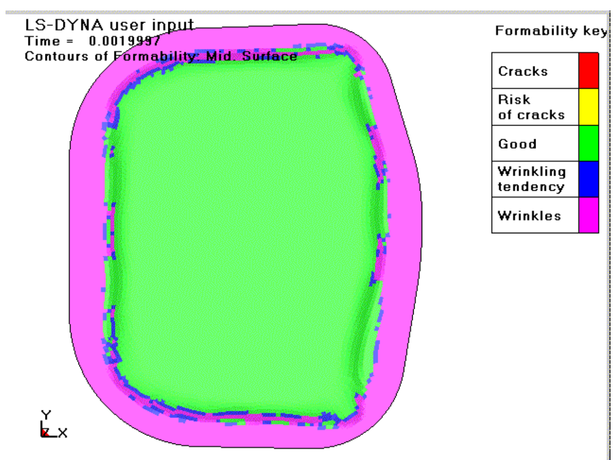


Fig. 7. Final view of the workpiece after the third category.

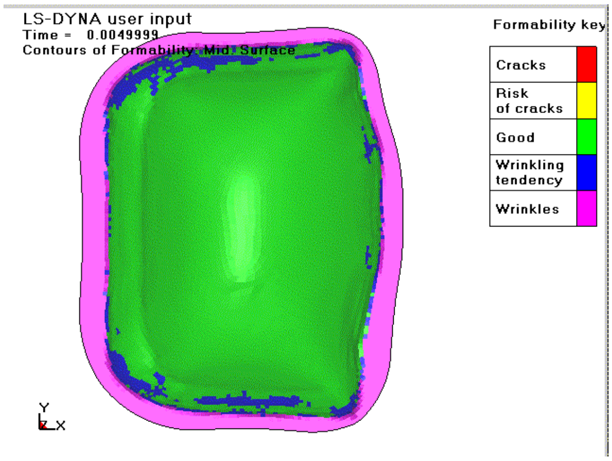


a)

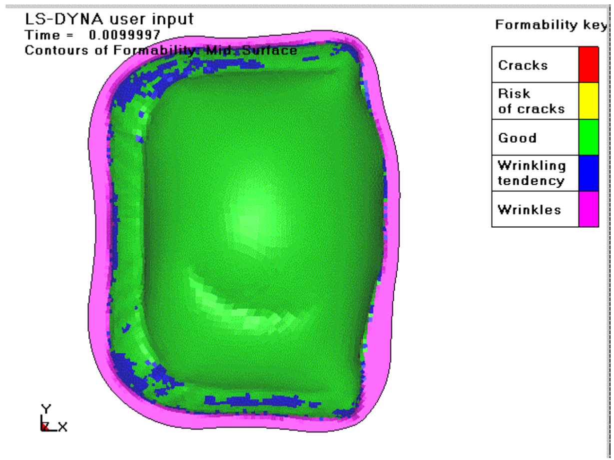


b)

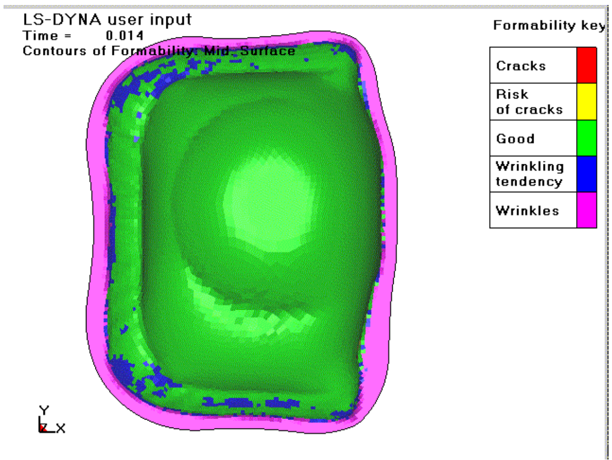
Fig. 8. Consecutive forming of the workpiece: (a) time = 0 s; (b) time = 0.002 s.



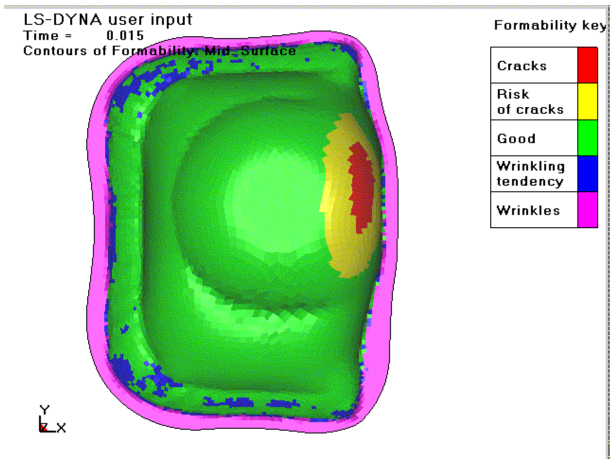
c)



d)



e)



f)

Fig. 8. Consecutive forming of the workpiece: (c) time = 0.005 s; (d) time = 0.01 s; (e) time = 0.014 s; (f) time = 0.015 s.

CONCLUSIONS

The stages of workpiece deformation during an electrichydroimpulse discharge in a large - volume chamber was considered. For preliminary calculations, a simplified axisymmetric deformation model was created. It was revealed that the amplitude of the discharge impulse strongly depends on the liquid volume in the chamber, and not on the shape of the electrode system. It is shown that the main change in the shape of the workpiece occurs under impulse loading at the initial stage of the discharge.

Based on preliminary calculations, the shape of the initial workpiece was optimized, and a surface model of the equipment and workpiece of complex shape was built. Calculations have shown that in a few discharges the workpiece completely fills the die shape, however, cracks appear at the bottom of the workpiece. The developed computer model of combined electrohydroimpulse forming made it possible to estimate pressure parameters and determine the required changes in process parameters to produce a specific sheet metal part.

REFERENCES

1. G.N. Zdor, L.A. Isaevich, I.V. Kachanov, Technologies for high - voltage metal deformation, BNTU, 2010, Minsk, (in Russian).
2. M.E. Taranenko, Electrohydraulic stamping: theory, equipment, technical processes, Harkov, HAI, 2011, (in Russian).

3. V.N. Chachin, Electrohydropulse processing of materials in mechanical engineering, Minsk, Nauka i tehnika, 1987, (in Russian).
4. V.N. Chachin, Electrohydropulse processing of engineering materials, Minsk, Nauka i tehnika, 1978, (in Russian).
5. E.V. Krivickiy, Dynamics of electric explosion in liquid, Kiev, Naukova dumka, 1986, (in Russian).
6. S. Lezhnev, E. Panin, A. Tolkushkin, D. Kuis, A. Kasperovich, Development and computer simulation of a new technology for forming and strengthening screw fittings, J. Chem. Technol. Metall., 58, 5, 2023, 955-960. https://doi.org/10.59957/jctm.v58i5.132.
7. F. Popov, N. Lutchenko, A. Panichkin, S. Lezhnev, E. Panin, L. Vinogradov, A. Arbuz, Modelling the evolution of casting defect closure by radial shear rolling, J. Chem. Technol. Metall., 59, 1, 2024, 197-206. https://doi.org/10.59957/jctm.v59.i1.2024.23.
8. A. Naizabekov, E. Panin, S. Lezhnev, A. Arbuz, A. Tolkushkin, M. Knapinski, A. Esbolat, Computer simulation of preliminary heat treatment and radial - shear rolling of copper, J. Chem. Technol. Metall., 58, 6, 2023, 1163-1170. https://doi.org/10.59957/jctm.v58i6.157.
9. J.O. Hallquist, LS - DYNA theoretical manual, Livermore, CA, Livermore Software Technology Corporation, 2006.
10. K.N. Bogoyavlensky, V.A. Vagin, V.S. Mamutov, V.V. Rhys, Hydroplastic processing of metals, Sofia, Mechanical Engineering, 1988, (in Russian).
11. V.S. Mamutov, G.N. Zdor. Mechanics of loading and deforming of thin sheet blank at electro - hydraulic forming, Int. Rev. Mech. Eng., 11, 5, 2017, 332-336. https://doi.org/10.15866/ireme.v11i5.11585.