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CREATING ALGORITHM FOR SIMULATION OF FORMING FLAT WORKPIECES

Konstantin Solomonov¹, Sergey Lezhnev²¹Moscow State University of Railway Engineering (Voronezh Branch), Voronezh, Russia, ²Karaganda State Industrial University, Temirtau, Kazakhstan

Abstract. Problems of creating of the algorithm and software for the simulation of some metal forming processes are considered. The results obtained in the simulation of the flow pattern of metal for processes of forging and stamping flat workpieces are represented.

Keywords: modeling, software

OPRACOWANIE ALGORYTMU MODELOWANIA FORMOWANIA PŁASKICH ELEMENTÓW

Streszczenie. Rozpatrzono problem opracowania algorytmu i oprogramowania dla modelowania pewnych procesów obróbki metali pod ciśnieniem. Przedstawiono wyniki otrzymane przy modelowaniu przepływu metali w procesach kucia i wybijania płaskich detali.

Słowa kluczowe: modelowanie, oprogramowanie

Introduction

Currently, for the development and optimization of the technology and tools for metallurgical and machine-building enterprises around the world software systems, designed for the simulation of metal forming processes (MF) are widely used and play a leading role.

All of CAE-systems for simulation of metal forming processes can be divided into three groups: widely-oriented (Ansys, Super-Forge, Forge, Abaqus, Deform), special (Qform, Splen) and specialized [6].

Widely-oriented CAE-systems can simulate almost all of metal forming processes, ranging from a simple crimping or upsetting, finishing deformation of multilayer material or explosion stamping, considering heat treatment, phase transformations and microstructural analysis of steels and non-ferrous alloys. Some of them are focused on solving the most complex and demanding nonlinear problems, as well as to conduct multidisciplinary static and dynamic analysis within a single algorithm.

Special software complexes (PC) allow to simulate the whole technological process, including preparatory and intermediate operations: heating, cooling, burr cutting, hole punching and directly metal deformation in the hot, cold and warm condition. These PC, unlike widely-orientated have a more limited application.

Specialized PCs are focused on simulation one or two of metal forming processes (for example, producing forged pieces in the processes massive stamping and forging). To such presented in this paper software can be attributed.

The advantages of widely-oriented and special PCs are: breadth of tasks; sufficiently high accuracy of the results, which is provided mainly by taking account many factors (temperature, rheology, material, etc.); friendly, convenient and simple interface.

As disadvantages of software products include: extremely high requirements to the parameters computer equipment; considerable time calculation and simulation of one variant, the relatively high complexity and low speed file creation of input data, costs on user training.

1. Problems of software complex development

Considered in this paper specialized PC for calculating parameters of the processes massive forming and forging and simulation of plastic form changing flat workpieces has the following advantages: low performance requirements of computer equipment, a high speed calculations; accelerated input initial information; quick and easy user training of staff. Providing these advantages PC is achieved by simplifying mathematical model and bringing the initial system of differential equations to the analytical dependences. As a consequence, there is a significant relief software implementation of calculation algorithm, but narrowing of the range of tasks. However, where express analysis

and fast (albeit approximate) evaluation of the plastic form changing the workpiece are required, such program can be an invaluable assistant.

Thus, the aim of the research is to create a simple to learn and operative to use PC for the simulation of plastic form changing metal in processes of massive forming and forging, capable to serve as an intelligent assistant to constructor and technologist. It should be borne in mind that the area of application of the considered here models in recent years rapidly expands: to "traditional" aircraft and rocket production automotive industry [2], car building and others join.

2. Mathematical model and calculation algorithm

In the processes of metal forming significant proportion flat forging is, shaping of which obeys the laws representing spatial epures form of contact pressures (SECP) a similar form of surface the same ramp [4]. In continuum mechanics description of the process form changing of material is known as "sand analogy" [3].

In this case SECP represents a surface of the same ramp, all the generators of which are inclined to the plane of the contact at the same angle.

The equation of this surface, characterizing the distribution of the generalized pressure P on the plane of the contact xy , is as follows [1]:

$$\left(\frac{\partial P}{\partial x}\right)^2 + \left(\frac{\partial P}{\partial y}\right)^2 = \frac{K^2}{h^2} = const, \quad (1)$$

where $P = \int \frac{dp}{2\tau(p)}$, where τ – shear stress.

By adding friction conditions and boundary conditions, the system of equations can be considered closed.

Conditions of friction at this depend on deformation scheme of the metal that in a production environment due to the choice of lubricant is largely:

- $K = 1, \tau = fp$ for $p \leq \frac{\sigma_T}{2f}$ in area of Coulomb friction,
- $K = 1, \tau = \frac{\sigma_T}{2}$ for $p \geq \frac{\sigma_T}{2f}$ in area of Prandtl's friction,

where f – coefficient of friction.

Boundary conditions characterize the magnitude of the contact pressures on the contour of the mirror of die impression stamp which can be: a) die cavity "dovetail", when a metal with almost no resistance flow into the die cavity, or when flowing into the cavity with a draft on initial stage of upsetting; b) die cavity with draft on the next stages of deformation, when flowing into the cavity metal due to high friction along the walls resists flowing; c) the initial workpiece form in plan.

Accordingly, the ratios for the calculation of the boundary contact pressure look like this:

$$p = \begin{cases} const & \text{at free flowing into the cavity} \\ k(s)\sigma_T & \text{at labored flowing into the cavity} \\ \sigma_T & \text{at free spreading by die impression stamp} \end{cases}$$

Here, $k(s)$ – resistance coefficient to metal flowing in the die cavity which characterizes the geometry of the die cavity or other structural elements of the stamp as well as the technological features of the process of deformation of the metal, s – parameter, defining the coordinate along the contour (Fig. 1).

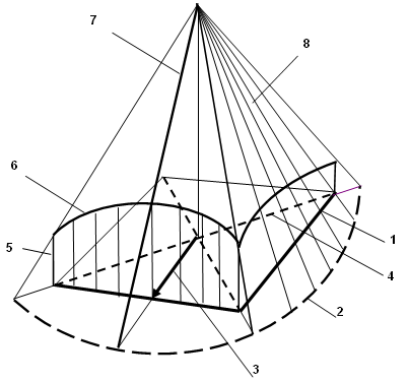


Fig. 1. Graphical interpretation of the model: 1 – contour of forging, 2 – conditional contour, 3 – stream line, 4 – dividing line of the metal flow, 5 – boundary contact pressure, 6 – epure of boundary contact pressures, 7 – line of slope, 8 – spatial epure of contact pressures

Because any multiply connected circuit with sufficient degree of accuracy can be approximated by straight lines and circular arcs, we can assume that the surface SECP consists of flat and conical sections. Line of their intersection form edges (so-called ridges).

Frontal and profile projections of these edges allow determining the volume of epures the contact pressures and therefore the force, required for deforming the metal, the horizontal projection (plan view) is a dividing line of the metal flow (DLMF), which characterizes the metal flow distribution on the contact surface.

It is obvious that DLMF is the equidistant, i.e. the geometric locus of points equidistant from the contour of the forging.

For controlling of metal flows along the bed the forging in processes of metal forming technological recesses or cutouts used, which allow preventing the number of defects («cross», unsatisfactory tie of fibers, «a sink mark») and also regulating volume distribution of metal over the area of the workpiece.

In the process of deformation of the workpiece the stream lines distort and by changing the slope of the contour, cease to be orthogonal to it. For simplification calculation equations is more convenient to introduce a conditional contour [5], in relation to which the streamlines are orthogonal, and identify the dependence of the shape of the conditional contour from the shape of epure of boundary contact pressures.

If to set a conditional contour by circular arc, which simplifies the mathematical model and consequently also formalization the entire problem, it remains to determine which form epure of boundary of contact pressures has.

Dependence of form conditional contour defined by a circular arc of radius R centered at (x_0, y_0) , from the form of the epure of boundary contact pressures can be expressed by the relation:

$$M_0^2 k^2 - 2M_0 kR + s^2 + 2x_0 s = 0, \quad (2)$$

where $M_0 = hf$.

For ease of analysis, we transform the resulting hyperbolic equation in general form to the canonical form:

$$\frac{(k - R/M_0)^2}{(y_0/M_0)^2} - \frac{(s - x_0)^2}{y_0^2} = 0. \quad (3)$$

Then the parameters $a = y_0/M_0$ and $b = y_0$ characterize the major and minor semi-axis of the hyperbola, and R/M_0 and x_0 determine the amount of displacement of the center of hyperbole about the origin.

Thus, if epure of boundary contact pressures is approximated by hyperbole, the problem of determining the parameters SECP is solved analytically.

For a quantitative estimation formation the workpiece solution of the problem is necessary not only for constructing DLMF but for determining the distance from DLMF to the contour which determines the length of stream lines, and consequently the quantity of metal flowing through the contour. In that case where the contour edges of rigidity limit, this distance determines the amount of metal, flowing into the cavity under edges of rigidity. Then the formation problem becomes a finished look.

Consider the statement of the problem in the scalar form. Let the contour consists of two parts, given an arbitrary smooth curve $y_1(x_1)$ and $y_2(x_2)$. Position of the line section of the metal flow, characterized by distances L_{T1} , L_{T2} from it to the contour, is determined by two conditions:

– of equidistance: $L_{T1} = L_{T2} = L_T, \quad (4)$

– of orthogonality: $L_{T1} \perp y_1(x_1), L_{T2} \perp y_2(x_2). \quad (5)$

Then, for determining the form DLMF we obtain the system of ordinary differential equations with respect to x, y, x_2 :

$$\begin{cases} (x - x_1)^2 + (y - y_1)^2 = (x - x_2)^2 + (y - y_2)^2, \\ \frac{dy_1}{dx_1} = -\frac{x - x_1}{y - y_1}, \\ \frac{dy_2}{dx_2} = -\frac{x - x_2}{y - y_2}, \end{cases} \quad (6)$$

where (x_1, y_1) – coordinates of the point, specified on the curve $y_1(x_1)$.

In general, the solution of this system is very difficult and does not have significant practical matter because contour of any forging are generally can be approximated by curves of the second order (circumference, hyperbola, parabola).

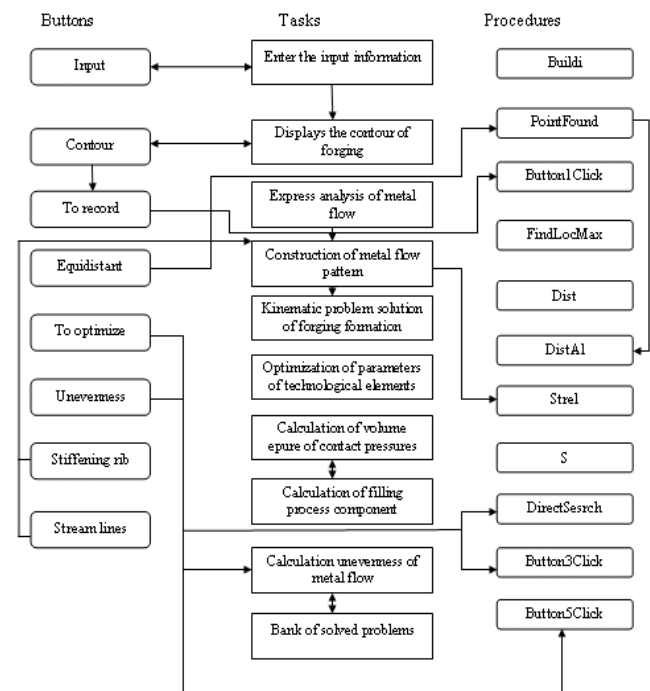


Fig. 2. Relations for calculating the boundary pressures

In particular, the distance from DLMF to contours in form in the circles of radius R_1 and R_2 , with the centers at a distance L , is determined from the relationship:

$$L_T = \frac{2LR_1 \cos \varphi - L^2 - (R_1^2 - R_2^2)}{2(R_1 - R_2 - L \cos \varphi)} \quad (7)$$

Here for calculating L_T is enough to choose only value of the angle L_T , which determines the position of a point on the contour.

Closed algorithm (Fig. 2) includes relations for calculating the boundary pressures.

3. Description of the program complex

On the basis received algorithm PC is designed, that allows you to construct: contour of the forging, DLMF, pattern of the flow metal, profile of stiffener, SECP, and also solve the problem of optimizing the combination of technological openings and recesses through which you can control the flow of metal (Fig. 3). Although substantially all of the theoretical issues have been resolved, however the software implementation meets a number of difficulties in connection with which the last three blocks of the program are being finalized.

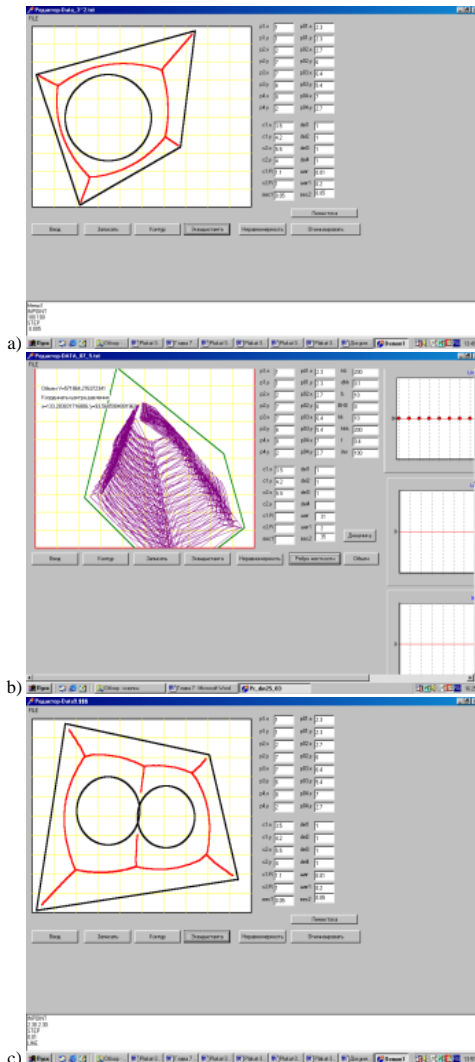


Fig. 3. The abilities of developing program complex

Presented PC consists of three main programs implementing solution of the static, kinematic and dynamic problems. Solution of the static problem is consistent with the principle of the shortest normal, according to which the metal to the contact plane flows along streamlines directed orthogonally to the contour of the forging. In this case DLMF is equidistant to contour of forging. Solution of kinematic problem based on the principle of least

perimeter, through which the radial flow scheme of metal can be adopted, characterized in that streamlines are orthogonally directed to some arbitrary curve, which is a level line on the surface of the contact pressures. Dynamic problem reduces to the construction SECP representing a combination of conical and hedral surfaces. Moreover, in projection on the plane of contact edge of this surface lines of section of the metal flow are and slope line – streamlines.

Data about the form of the workpiece are formed as follows. First, in schematic form contour forging is drawn, whose shape is determined by a pattern of the die cavities under stiffening ribs and lugs in the plan.

Then the values of individual geometric primitives are taken (lines and arcs of circumferences). Additional description data are entered in the input file, and the calculation is performed.

Enter the details of the geometry of forging is carried out fairly quickly and simply: at first contour of real forging is approximated by straight lines and circular arcs, and then they are numbered, after information is entered in the input file in random order. There also data about step of calculation is placed, about position the starting point, for each segment of the line – the coordinates of the beginning and end of the segment, for each arc of a circle – the coordinates of the center, radius and apex angle (Fig. 4). Time of produce a result takes a few seconds.

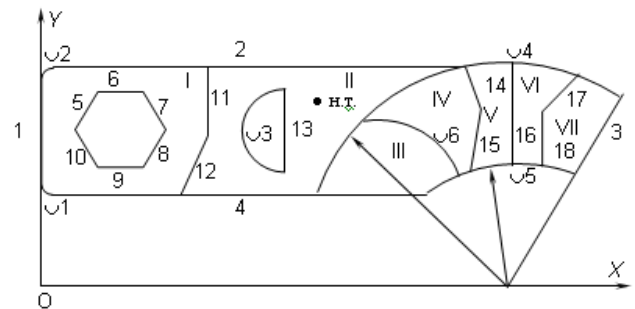


Fig. 4. Formalization of contour of forging

For several serial forgings simulation results of metal flow pattern throughout bed workpiece are obtained (Fig. 5), which is determined mainly by DLMF position.

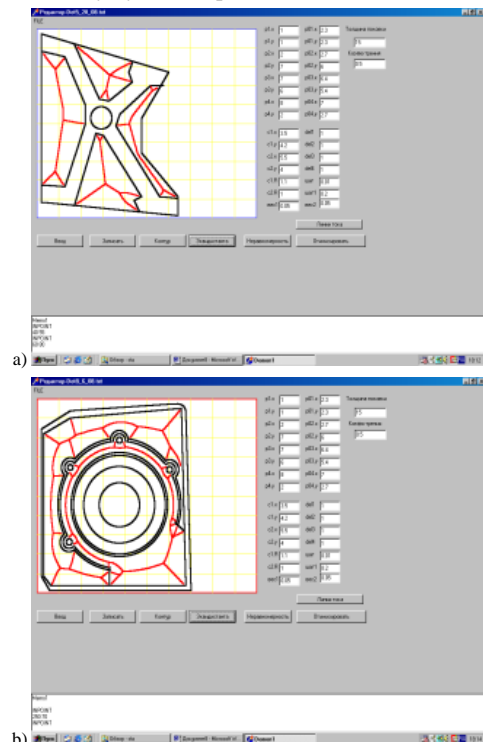


Fig. 5. The pattern flow of metal for the serial forgings in plan

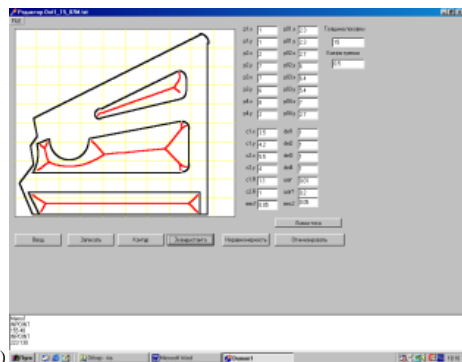


Fig. 5 (cont). The pattern flow of metal for the serial forgings in plan

4. Comparison of calculation results

For simulation SECP and DLMF widely acclaimed graphics editor KOMIAC can also be used, because "squirting" of the solid model in this graphic package is made so that all the generatrices obtained surface are inclined at the same angle to the plane of the contour. Consequently, the solid model – is a surface of the same slope, similar in shape SECP. During the transition to drawing horizontal projection of this model reproduces the shape DLMF. Comparison of the results obtained in KOMIAC and developed by us PC, shows good coincidence with the physical experiment (Fig. 6).

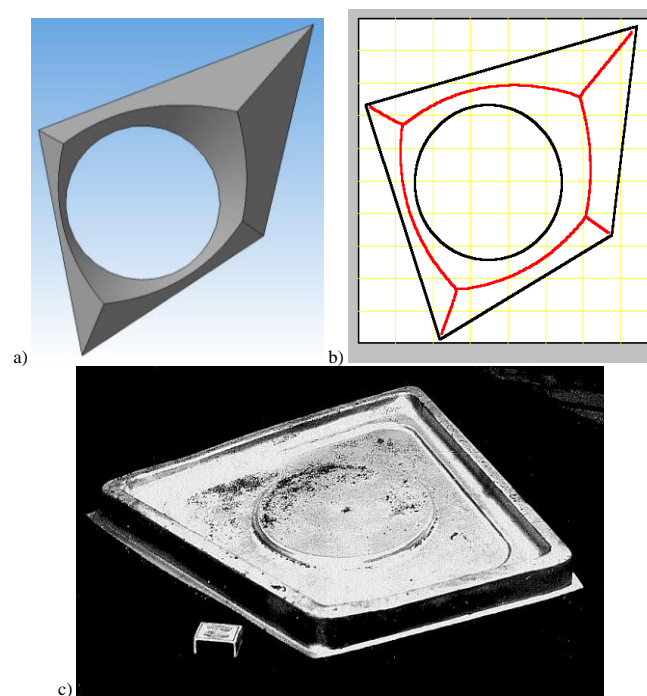


Fig. 6. The simulation results: a) in KOMPAS, b) in the developing PC, c) in industrial environments

In order to use developing Program Technical Complex "Express analysis of plastic forming of metal in the metal forming processes" for the simulation of real processes, its modification and completion are made, carried out in the framework of international cooperation under the "Grant research funding for 2013–2015" of Ministry of Education and science of the Republic of Kazakhstan.

Completion, as indicated above, is to debugging the last three blocks of the PC: calculating and imaging of profile edges

of rigidity at all stages of upsetting workpiece; construction of SECP; solving the optimization problem of combination and the location of technological components.

For full automation simulation and predicting of the plastic material forming in processes of bulk forming and forging, as well as solution of design and technological problems by developing modification of the PC is suitable, representing the creation of three additional blocks: intellectual, implemented in the form of an expert system; infological, consisting of databases on the enterprises, processes and materials, and equipped with the appropriate DBMS; electronic libraries, filled with information of design and technology plan.

5. Conclusions

Widely-oriented and narrowly-oriented program complexes complement each other. Widely-oriented designed for decision of complex technological and design problems with a wide range of simulated metal forming processes, a large number of defined parameters as close as possible to the real conditions of production. They require, as a rule, considerable financial and human resources. Specialized (such as the developing program complex) are very limited in their ability to simulating of technological processes, however, allow to quickly get the results, are easy to learn and use and do not require great expenses at their implementation.

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Prof. Konstantin Solomonov
e-mail: konssol@list.ru

Author of more than 200 papers which were published in scientific journals of Kazakhstan, Russia, Czech Republic, Poland, China, Japan.



Ph.D. Sergey Lezhnev
e-mail: sergey_legnev@mail.ru

Author of more than 140 papers which were published in scientific journals of Kazakhstan, Russia, Czech Republic, Poland, Bulgaria, China, Germany, Japan. Also author of 21 patents for various methods and technologies of metal deformation. Twice winner of the State scientific grant for talented young scientists (2008–2010, 2010–2012) and the Governmental scholarship for academics and professionals who have made outstanding contributions to the development of science and technology (2013).



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