Simulation of deformation processes in upsetting

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Abstract. The article describes an analysis of universal and specialized software complexes. We consider the «equi-theory» used for simulating the metal flow pattern. The software complex EQUI is applied to computer simulation of the metal flow pattern. We show how it is used for complex multi-contour workpieces.

1. Introduction
Plastic deformations can be considered irreversible in comparison with elastic deformations when the material regains its previous structure. Since the pure elastic deformation does not exist in either nature or technology, all deformation processes can be considered irreversible in this respect. Various methods of metal forming constitute such processes which involve plastic deformations. Some of them - forging, die forging and sheet rolling - are described by the deformation scheme of upsetting that specifies the reduction in a workpiece size towards the loading force with a further increase in two other sizes determining the workpiece dimensions in the plan.

In this case, the workpiece shaping is mainly determined by the metal flow moving along its web and therefore is simulated by the metal flow pattern.

2. The problem statement
Available universal software complexes allow simulating almost all metal forming processes, ranging from simple workpiece bending or upsetting to the deformation of multilayered materials or explosion stamping, with the heat treatment, phase transformations, and micro-structural analysis of steel and nonferrous alloys being taken into account.

Special software complexes encompass the whole technological process including both preparatory and intermediate operations such as heating, cooling, trimming, punching holes, and the deformation of metals itself: hot, cold and warm working. Unlike the universal software complexes, these complexes have more restricted application.

The choice of a certain type of CAD/CAM systems for either designing or analyzing processes largely depends on the enterprise feasibility. Moreover, it should be noted that current trends in the development of CAD/CAM systems result in arising more opportunities for their integration into other systems, as well as export or import of databases.

Nowadays, there are many CAD/CAM systems of various analyses of geometric objects at the design stage. Most of them are based on the well-known finite element analysis but it needs improving. One of its drawbacks is the difficulty in perceiving all the details and peculiarities of the
pre-setting conditions of a certain process, whereas understanding of basic principles and properties of geometric objects, such as the same slope surfaces, facilitates the design process thus improving the product quality.

*Universal and special software complexes* possess a number of indisputable advantages. First, they are able to deal with a wide range of active tasks. Second, they have a simple intuitive interface. Third, they ensure a high accuracy of the obtained results. There are, however, a number of drawbacks. We can signify the following ones: sufficiently high requirements for computer equipment specifications; both the complexity and low speed of creating a file for input data; long-lasting user training courses; considerable waste of time to compute and simulate one option. For example, the stamping process in the SolidWorks system can be simulated for several hours. Moreover, such systems are very expensive.

*Specialized software complexes* targeted at simulating one or two metal forming processes have the following advantages: low requirements for computer equipment specifications; high computational speed; enhanced data input; easy short-term user training courses. It should be noted that over recent years, possible implementation areas of these complexes have been significantly broadened from the «conventional» aircraft, rocket and missile manufacturing industries to the automotive and car ones.

When creating software products, it is necessary to consider a particular user’s possibilities, as well as concentrate on the computer system functionality and resources saving. In this regard, some modern enterprises decide to develop their own specialized software complexes targeted at both performing particular tasks and avoiding the drawbacks mentioned above.

3. The research goal and objectives
The goal of this research is to design and develop a software complex which is capable of simulating the forming of multi-contour forgings.

The goal suggests working out the following objectives:

– drawing a multi-contour workpiece on a given sizes;
– plotting a dividing line of metal flow, which is an equidistant of the workpiece contour;
– tracing a conditional contour, which determines the direction of metal flow lines;
– plotting metal flow lines directed perpendicular to the conditional contour;
– using technological and constructional units.

4. Basic principles of the «equi-theory»
We have formulated the «equi-theory» which helps us to solve these problems. We described the basic principles of the «equi-theory» in detail in [1]. Here we give a gist of them as follows.

4.1. The principle of the shortest normal current line
The principle of the shortest normal current line determines the current line direction orthogonal to the contour of the forging, which represents a sudden change in the layer thickness (including stiffening ribs or elevations on the forging blade). Hence, at the initial stage of deformation, when the terminal pressure remains the same along the boundary contour, the metal flows move orthogonally to the contour and the amount of the flowed metal at each point on the boundary is defined by the length of the current lines.

4.2. The process of deformation
In the process of deformation, the boundary conditions change, thus the contact pressures become unequal along the contour. In this regard, the current lines will be directed at an acute angle to the contour of the forging. However, considering the fact that a spatial diagram of the contact pressures is a ruled surface, both the fall and current lines are directed orthogonally to the level curves of this surface. By projecting the three-dimensional pattern onto the plane of the forging blade it becomes possible to add a conditional contour along which the contact pressures are equal. Then the flow lines are orthogonal to this conditional loop.
4.3. The contour of forging
Since the spatial diagram of the contact pressures is the surface of the same slope, the line section of metal flow is the locus of points equidistant from the contour of forging. The contour of forging can be approximated by straight lines and circular arcs. Therefore, the problem of constructing a line section of metal flow is reduced to finding the locus of points equidistant from the circles and straight lines.

5. Advantages of software complex EQUI
Based on the «equi-theory», the algorithm [2] and the specialized software complex EQUI were developed. It allowed us to simulate the metal flow pattern in both the forging and die forging processes, in which the deformation scheme of upsetting is observed [3].

This software complex has the following advantages. First, it is fast, simple, and less demanding of computer equipment specifications. Second, creating a file for input data takes several minutes. Third, computation time being spent on one option is several seconds. Fourth, the high computation speed is achieved by simplifying the mathematical model and the initial system of equations. This narrows the range of tasks and metal forming processes. It also reduces the system of differential equations describing the material stress-strain state to analytical dependencies.

In addition, the software complex EQUI allows simulating a spatial diagram of the contact pressures, thus facilitating the estimation of the total press efforts which are necessary to deform the workpiece. This simulation becomes possible due to the fact that a spatial diagram of the contact pressures is similar to the equal-slope surface.

6. Computer simulation of the metal flow pattern
We discussed the computer simulation with the help of the software complex EQUI for single-contour workpieces in [1].

Some recent improvements to the software complex EQUI make it possible to simulate the metal flow pattern of the complex multi-contour workpieces (see Figure 1) which allows us to trace a contour of the workpiece, plot both the dividing line of metal flow and the flow line, as well as determine the position of technological and constructional units. The latter permits us to control the metal flow.

The figure does not show the conditional contour, since the metal flow pattern is depicted at the initial moment of deformation when the conditional contour coincides with the real one.

7. Conclusion
The analysis of the metal flow pattern which has been obtained with the help of the software complex...
EQUI allows us to argue that the technological cutout provides more uniform metal flow. Consequently, it becomes possible to obtain the forging with a better macrostructure.

References
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