Simulation of forming a flat forging

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Abstract. The metal flow in some of the metal shaping processes (rolling, pressing, die forging) is subjected to the regularities which determine the scheme of deformation in the metal samples upsetting. The object of the study was the research of the metal flow picture including the contour of the part, the demarcation lines of the metal flow and the flow lines. We have created an algorithm for constructing the metal flow picture, which is based on the representation of the metal flow demarcation line as an equidistant. Computer and physical simulation of the metal flow picture with the help of various software systems confirms the suggested hypothesis.

1. Introduction

The blank parts with thin blades are produced at the special production facilities of iron and steel plants equipped with powerful pressing machines. Such products often have flaws which worsen their macrostructure. Therefore it is of great current interest to find new techniques of simulating the forming processes for forgings with stiffening fins.

It is hard to make a mathematical model of metal forming processes, which would describe the mode of deformation of metal plastic forming. One way to solve the problem of simulating the metal flow pattern and the spatial pressure profile is a so-called «theory of thin-layer flow» [1]. It is based on the assumptions which simplify the original system of differential equations. Therefore the problem comes to purely geometric tasks and can be solved in terms of the so-called «sand analogy» using the suggested technique [2].

2. The basic provisions of the developed method

This method is based on the following provisions [3, 4]:

- 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 flowed metal amount at each point on the boundary is defined by the length of the current lines.

- In the process of deformation the boundary conditions change and along the contour the contact pressures become unequal. In this regard, the current lines will be directed at an acute angle to the contour of the forging. However, given the fact that the spatial diagram of contact pressure is a ruled surface, the fall lines (and so the current lines) are directed orthogonally to the level curves of this surface. Projecting the three-dimensional picture on the plane of the forging blade it is possible to add a conditional path along which the contact pressures are equal. Then the flow lines are orthogonal to this conditional loop.

- In general, the conditional contour is a rather complicated curve. In accordance with the principle of the least perimeter slab tends to take the form of a circle in the plan. Therefore, we can assume that
the flow lines are directed along the radii of a circular arc. Then the conditional contour is a circle, and
the flow pattern of metal on the forging web will be radial.

- Note that the radial flow pattern of the metal is more universal than normal. It is also applicable in
the initial stage of deformation for the forging when its circuit consists of the curved lines sections.
Approximating the contour of forgings with circular arcs you can also apply a radial circuit at the initial
moment of deformation when the current lines are perpendicular to the contour.

- In view of the above, the spatial diagram of contact pressure is a combination of conical surfaces
at any stage of the workpiece deformation except the initial one. Concurrently, the boundary contact
pressure is lying in the vertical planes intersecting these surfaces.

- The value of the boundary contact pressure at any time point for any deformation in the arbitrary
point on the contour depends on several parameters: the thickness of the forging blade, the sizes of the
die cavity, the gutter width and the amount of the metal flowed into the cavities. Consideration of all
these parameters entails using rather complex formulae to calculate the boundary contact pressure.

- Since the spatial diagram of contact pressure 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.

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

- Frontal and profile projections of these edges allow determining the volume of the contact pressure
diagram and therefore the force, required for deforming the metal. The horizontal projection (plan view)
is a dividing line of the metal flow, which characterizes the metal flow distribution on the contact sur-
face.

3. A new algorithm for constructing the equidistant

Most of the parts used in mechanical engineering, in view of technological design requirements, consist
of the revolution surfaces and polyhedra. Therefore, in the practice of die forging a lot of parts produced
from flat blanks have planar elements. In this article we shall confine ourselves to the simplest case: we
shall consider the problem of constructing an equidistant for the contour which represents a piecewise-
linear closed line, i.e. polygon (Fig. 1, a).

![Fig 1](image1.png)

**Figure 1.** The scheme of constructing an equidistant

The equidistant of two lines is the bisector of the angle. Therefore, the very first equidistant contour
line is the bisector of the smallest angle at the apex D. Then hold the bisector of two adjacent angles (C
and E) to the intersection with the bisector of the smallest angle (points G and H). The first equidistant
lines finish at the nearest point G of the intersection with the bisectors of the adjacent angles.
Next, we eliminate from consideration the direction DE. The bisectors of the angles adjacent to the direction DE have formed the equidistant lines. Continue to the intersection side FE and CD adjacent to the dropped line.

The dimension of the contour has decreased per unit: instead of the hexagon we shall now consider a pentagon. It is evident that now the smallest angle in the polygon of the contour is a newly obtained angle. The procedure is repeated, but the new equidistant line is built from the end point of the last equidistant line (point G) rather than from the angle of the contour. Then again look for the smallest of the remaining angles of contour (i.e. the angle at the vertex F) and repeat the above-described algorithm until the polygon is reduced to the triangle. As we know from geometry, the bisectors of the triangle always intersect at one point, so to finish the construction of equidistant lines it is sufficient to connect the points in which the stop of the sequential actions took place. The construction is completed (the result is shown in Fig. 1, b).

In a similar way, one can construct an equidistant of any polygon. Currently, this algorithm is implemented in the visual programming environment DELPHI.

A similar algorithm was developed for the multivariable piecewise-nonlinear contour [5].

4. Computer-generated simulation

The following example of simulating the forming of closed die forging with contour finning shows the potentialities of the developed method and software package (Fig. 2).

![Figure 2. Forging with a technological cut-out](image)

For express analysis of a lug (or a notch) application expediency in this forging, a metal flow pattern with different circle center positions and radii has been simulated by means of the developed software complex [6]. The end-point analysis shows that the metal outflow to the lug (or the notch) reduces the unevenness of metal flowing into the die cavity. Therefore its application is advisable.

A program based on the developed method has been used for simulating the forging.

When simulating the following requirements should be taken into consideration. We can change only those geometric elements which do not influence the product design, for example, the width and height of the gutter, the lug radius, the initial thickness of the primary blank or upsetting stage. The lug radius belongs to these variables because it should be replaced by a 240 mm hole in the fine product and the lug can be removed during machining. In the calculating process the lug size is the controlling factor which allows getting different metal flow patterns on the die impression surface and different stiffening rib profiles.

Fig. 3, a shows the pattern of the metal flow along the forging cloth.
Similarly, we can get the metal flow picture for any complexity of the contour (Fig. 3, b).

![Figure 3. Metal flow picture model](image)

**5. Physical simulation**

To test the simulation results of forming the closed die forging with the contour finning we have conducted an industrial experiment (Fig. 4) on stepwise upsetting of the flat forged primary blanks made of AK6 alloy by means of a hydraulic press of 150 MN deforming force.

The full forging was not achieved because of the low power of the hydraulic press. At the last step of upsetting the lug was entirely formed whereas one of the stiffening fins angular areas didn’t reach the estimated height. (Fig. 4, d).

The central areas of stiffening fins are formed much quicker than the angular ones, which results in metal flowing above the die cavities under the stiffening fins in the central areas and worsens the product macrostructure (Fig. 5, a). The figure shows that the fin was cut from the side of the groove.

The application of the software complex for simulating different technologies in order to obtain the given serial forging served as a proof. As it was stated above, the forging could not be formed in one step with the technique suggested by the factory.
The calculation analysis provided recommendations for the die design and mass production technology. As the use of the lug of a big radius does not eliminate nonuniformity of certain stiffening fins, which may result in flaws forming, it is suggested that die forming should be performed in two steps in one final die, with cutting a hole in the centre of forging after the first step. Industrial die stamping with account of the recommendations has proved their appropriateness: the force of the hydraulic press of 100 MN (Fig. 2) power was enough to produce a quality product; whereby the die forging macrostructure was significantly improved (Fig. 5, b).

Summary

The software complex may perform different functions: express analysis of the metal flow picture, the calculation of primary blank deformation at each stage, which makes it possible, while examining the values of die impression geometric parameters, to obtain various metal flow patterns and stiffening fin profiles, and to select those providing the most uniform metal flow into the die cavity under the stiffening fins, which ensures flawless product manufacturing.

References

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