The clamps of sheet blank movement trajectory simulation under the shell part stretch forming process

V A Mikheev, A F Grechnikova, Roberto de Alvarenga and M M Demidova  
Samara National Research University, 34, Moskovskoye shosse, Samara, 443086, Russia  
E-mail: vamicheev@rambler.ru

Abstract. The main object for analyzing the results of modeling and optimizing the shaping method by the skin is the graphs of the change in thickness at characteristic or selected points on the surface of the shell of double curvature. The article discusses two variants of the method, which have the same cyclic diagram of step movements of the main and auxiliary working cylinders of the stretch-tightening press RO-630-11. Both options contain kinematic techniques that implement the following two effects. The first is the effect of isometric bending of the shell surface after unloading the sheet blank at the third step motion of the press according to the cycle diagram. The second is the effect of the forced position of a flat and sufficiently long sheet blank in rectilinearly arranged discrete clamping devices of the press. This provided a plastic deformation of the middle part of the sheet blank without localizing the thinning deformation and the alignment of its values in different zones of the sheet blank.

1. Introduction  
The essence of the shaping process is that a flat sheet blank is transformed into a spatial shell part under the influence of tensile forces from the moving clamps of the press located at its two narrow opposite ends. The sheet blank is plastically deformed by stretching, but not all at once; it adheres tightly to the surface of the tightening punch and gradually takes the shape of this surface. The main condition for obtaining a shell part of the required geometric shape is the stretching of all sections of the sheet blank to the state of plasticity [1].

Shaping refers to the shaping operations associated with increasing the area of the sheet blank due to the thickness of the sheet. There is a possibility of localization of stretching of the sheet blank in the dangerous section of the part. As a result, the sheet blank is quickly thinned and destroyed, which is the reason for high rejects and large technological waste. The reason for the localization of stretching of the sheet blank is, first of all, the unevenness of the deformation due to the influence of friction forces and the complex shape of the shell. Most often, the localization of stretching during stretching occurs at the section of the sheet blank from the stretching punch in front of the tightening press clamping devices. In this case, the thinning of the sheet blank, which occurs during the covering, does not depend on the covering scheme itself, but depends on the friction conditions, thickness, the nature of anisotropy, and the deformation characteristics of the rolled sheet.

To ensure the monotony of deformation, the shaping of the sheet blank must be carried out under symmetric stretch conditions without its localization in the part of the sheet blank located between the edge of the stretch punch and the clamping jaws of the press. The stretching of a sheet blank during
shaping by a wrapping differs not only in the magnitude of the forces, but also in the area of their application along the edge of the blank. In this case, the zone of plastic deformation on the sheet blank is outlined only on one side in the direction of tension, and the second, implicit boundary is the transition between the zones of plastic and elastic deformation, which is established by calculation or experimentally based on the analysis of the physical essence of the process [2,3].

The directions of movement of the boundary of the plastic deformation zone can be changed by moving the clamps of the sheet blank along a certain trajectory. To do this, it is necessary to coordinate the nature of the movement of the working bodies of the tying press by programming. The kinematic grounded schemes for shaping the shell of the considered geometric shape by a wrapper are associated with the fact that the tensile force applied to the discrete clamps is perceived by the workpiece along the clamp width. This feature affects the «picture» of the center of plastic deformation, which will be different depending on the rectilinear or curvilinear position of the discrete clamps on the clamping plate of the press [4].

To maintain the stability of the plastic state of the shell, it is necessary to prevent the appearance of bending deformation of the middle surface due to the application of external forces in the tangential direction at the section of the sheet blank coming off the surface of the tightening punch. The middle surface, reduced to the vertical planes of symmetry due to the orientation of the surface relative to the curvature lines, will ensure the constant position of the shaping contour of the surface of the shaping punch in the vertical plane of symmetry of the shaping press, as well as the perpendicularity of the plane of the shaping plate of the shaping press to the horizontal plane of the sheet blank at the vanishing point of the shaping contour of the shaping punch.

Stable control of the shaping processes by the skin is based on the initial position of the plastic deformation zone in the central zone of the sheet blank. The shaping of the sheet blank according to one or another kinematic scheme is accompanied by the oncoming movement of the boundaries of the plastic deformation zone while maintaining the location of the greatest deformations in the central region of the sheet blank. This allows you to increase the degree of deformation with a minimum probability of sheet breakage in one of its free sections between the edge of the punch and the press clamps.

Geometric study of the shaping punch to implement the conditions of symmetric shaping will make it possible to quickly perform complex calculations of the parameters of shaping processes even without the use of the traditional finite element method, which is characterized by the duration of calculations and a relatively high probability of error [5]. However, the achievements of modern information technologies, which raise the level of production and non-production technologies based on the digital twin - the digital representation of an object, have already led to the need to use existing developments in the field of storing information, operating with it and applying it in various fields.

The development of new methods of shaping by a stretch is to a certain extent restrained by the poor knowledge of the rheology of the behavior of the aluminum alloy in the annealed, and especially in the freshly quenched state. Due to the sheet texture formed during rolling, aluminum alloys are more prone to the predominant development of deformation along the sheet thickness or to thinning [6]. This tendency can be minimized to the recommended limits by creating a favorable texture of the sheet during the rolling process. This is a kind of guarantee for the stable control of the wrapping forming processes. For this, the correspondence of the texture axes of symmetry of the properties of the sheet blank and the directions of the lines of curvatures of the shell of double curvature intersecting at the pole of the surface of the covering punch was provided [7].

Under conditions of symmetrical wrapping, it is possible to reduce the likelihood of corrugations and breaks, which creates a solid basis for controlling the shaping processes by the wrapping, and increases the degree of shaping of the sheet blank, which is achieved practically in one pass without localizing the thinning deformation and leveling their values in different zones of the sheet blank. To do this, you only need to correctly position the pulling punch on the press table and know the trajectory of the clamps relative to its shaping contour and its location in the vertical plane of symmetry of the pulling press. The above principles of fulfilling the conditions of symmetric wrapping were used by us in modeling the shaping of a wrapped shell part by moving the clamps of the sheet blank along a certain trajectory.
2. Results of modeling the process of shaping by a wrap

The initial stage in the modeling of the process is the preparation of geometric models of the elements involved in the shaping of the tight-fitting: sheet blank; cover punch and double curvature shell in the LS-DYNA software package. The initial data for these elements was obtained from the enterprise. Sheet billet made of aluminum alloy 1163RDMV, 1.5 mm thick and dimensions in terms of 1880x10500 mm. The mechanical properties of this alloy were obtained during testing of five samples and statistical processing of the results: ultimate strength - 174 MPa; yield point - 78 MPa; uniform elongation - 18%; elastic modulus - 241.4 MPa and anisotropy coefficients $\mu_{21} = 0.428$ and $\mu_{12} = 0.40$.

Initially, it should be noted that the preparation of geometric models of elements for the calculation in LS-DYNA is carried out in the LS-PREPOST program. All geometry is exported to the program in *STEP format for further processing, which is presented in the form of creating a mesh, specifying the main parameters, generating an output calculation file, and so on. We omit the details of the preparation of the initial data here and show only the results of the geometric study of the covering punch and for visualizing the picture of the simulation results in kinematic steps due to the trajectory of movement of the clamps of the sheet blank. The main object for analysis and optimization of the method will be graphs of thickness changes at characteristic or selected points on the surface of the sheet blank. The tightening punch after geometric processing with symmetrical positions of the shaping contour, the central cross-section and the «pole» of the surface relative to the longitudinal axis of tension during tightening is shown in figure 1.

When describing the method of shaping a sheathing part by means of moving the clamps of a sheet blank along a certain trajectory, it is necessary to provide the results of a change in thickness during shaping by a shaping at the points we have designated on the surface of the sheet blank. The sheet blank is located in the initial position relative to the covering punch, starting from the edges A, B and C along the left contour of the part; the middle between the left contour of the part and the central section D, E and F; central section G, H and I; the middle between the center section and the right contour of the part J, K and L; the edge of M, N and O along the right contour of the part (figure 2). These points are located on three lines located on the sheet front front (blue), center (red) and back (green) in relation to the position of the press operator. The points of the «blue» and «green» lines correspond to the elements of the modeling grid located next to the line of the side contour of the part, the so-called trimming of the part by the contour template.

![Figure 1. Tightening punch after geometric processing with symmetrical positions of the shaping contour, central cross-section and «pole» of the surface relative to the longitudinal axis of tension during stretching.](image-url)
Figure 2. The points we marked on the surface of the sheet blank to identify the results of the thickness values.

The diagram in figure 3 indicates the initial position of the flat sheet when aligning the longitudinal axis of tension relative to the shaping contour of the tightening punch with the rectilinear position of the discrete clamping devices of the press. The longitudinal axis of tension coincides with the texture axis of symmetry of the sheet stock properties.

Figure 3. Alignment of the longitudinal axis of tension relative to the shaping contour of the tightening punch in the rectilinear position of the discrete clamping devices of the press.

The «black» arrows highlighted in the figure correspond to the main shaping movements of the stretching press (extension cylinders and table cylinders). The left and right clamps are mounted on clamping plates, which are pre-tilted by means of pivot cylinders, ensuring that the sheet blank is wrapped around the forming contour of the drawing punch when the press table moves upward by a
certain amount. Then stretching cylinders are turned on, which occupy a stationary horizontal position in the left and right base carriages of the RO-630 11 press (figure 4).

![Figure 4. Main working cylinders of stretching and press table, left and right base carriages, left and right rotary clamping plates with installed discrete clamping devices, cylinders for setting the clamps along the contour and cylinders of rotation of the clamping plate of the RO-630 11 press.](image)

Two variants of the method of shaping a wrapped part by means of moving the line of clamps of the sheet blank along a certain trajectory are proposed for discussion, having the same cyclic diagram of step movements of the main and auxiliary working cylinders (figure 5), where the indices of the kinematic state of the press and the conditional time of calculation are shown in circles.

![Figure 5. Cyclic diagram of the step movements of the main and auxiliary working cylinders of the press.](image)

The cycle diagram does not show the initial installation of the sheet stock into straight-line discrete clamping devices. Other default settings are present in the cycle diagram and are indicated. For example, for a clamping plate: [0] - the initial position is vertical; [1] - inclined installation position; for a press table with a tightening punch, 0 - zero position of the press table, when the "pole" of the tightening...
punch has a «tight» contact with a horizontally positioned sheet in clamping devices, for discrete clamps: [0] - initial rectilinear arrangement; [1] - curvilinear installation position and for stretching cylinders: 0 - horizontal position and extended plunger at a distance that ensures the initial installation of the sheet blank into straight-line discrete clamping devices.

The first variant of the method relates to the case when all the clamps are triggered, ensuring full gripping of the left and right edges of the sheet. The second variant of the method refers to the case when, for each base carriage, the central and two adjacent clamps are not turned on, leaving a part of the left and right edges of the sheet free. This variant of the method is able to reduce the difference in thickness values between the central part and the edge of the sheet that occurs during the shaping process. The cyclic diagram of the step movements of the main and auxiliary working cylinders of the press for both variants of the method is the same (figure 6).
The first step movement (from state 1 to state 2) - turns the left and right clamping plates into the setting state and the table movement up to a value of 470 mm to ensure the wrapping of the sheet blank along the forming contour of the tightening punch. During wrapping, the pre-stretched blank remained forced flat with discrete clamping devices in a straight line. This state of the sheet blank provides its initial configuration of a sufficiently narrow central region in accordance with the amount of curvature at the pole of the surface of the covering punch.

The second step movement (from state 2 to state 3) - the extension cylinders are switched on at the moment of the end of the rotation of the clamping plate and the movement of the table upwards. Plastic stretching of the wrapped sheet blank along the shaping contour of the tightening punch fixes the longitudinal curvature and the subsequent plastic configuration of the sheet blank, increasing the plastic
deformation zone of the central part towards the clamps and practically covering its width, remained forcibly flat with straight-line discrete clamping devices.

The third step movement (from state 3 to state 4) - the table is lowered simultaneously with stretching of the sheet blank due to the continuation of the stretching cylinders to a value of 65 mm. At this step, due to isometric bending of the sheet blank, which leads to an increase in the transverse curvature in its central part, the lateral sections of the sheet blank (frontal and rear lines) are significantly stretched, while the center line is not stretched. As a result of this effect, the transverse curvature is plastically configured and the convergence of the values of the thickness of the sheet blank in the transverse direction is observed.

The fourth step movement (from state 4 to state 5) - the table is raised to a value of 395 mm, the stretching cylinders do not work. The gradient of stretching of the sheet stock along the center line increases, while maintaining the boundaries of the plastic deformation zone without sliding towards the clamps, reducing the likelihood of breaking the sheet blank at one of its free sections between the edge of the punch and the press clamps. The values of the equivalent plastic deformation in the middle part of the sheet blank confirm the obtaining of the geometric shape of the shell with the corresponding curvature.

The fifth step movement (from state 5 to state 6) - the cylinders are turned on to set the left and right discrete clamps along the corresponding circuits to the setting state. The diagram shows a normalized value from 0 to 1, with a total clamping angle of 63 degrees on the left press base and 78 degrees on the right press base. Provides a tight clamping of the corner parts of the sheet blank to the surface of the tightening punch.

Sixth step movement (from state 6 to state 7) - stretching cylinders are switched on to a value of 100 mm and the table rises up to a value of 425 mm. As a result, the sheet blank, which received a full plastic configuration at the previous steps, undergoes plastic stretching of the corner parts pressed at the fifth step and a calibration adjustment of the conformity of the surface of the molded shell to the surface of the tightening press, i.e. completely lay down on the tightening punch.

When simulating both variants of the shaping method by the wrapping, we adhered to the specified sequence of step movements by moving the line of clamps of the sheet blank and preserving the parameters of the state of the equipment, determined by the sequence and values of the displacements of the working bodies of the wrapping press PO-630 11. The choice of two variants of the method was planned to test their effectiveness in order to achieve the main goal in understanding the achievement of the geometric shape and the minimum thickness difference of the double curvature shell.

When the RO-630 11 press is in operation, the displacements of the plungers of the left and right stretching cylinder must be monitored. When shaping the wrapping of the shells that are symmetrical with respect to the "pole" of the wrapping punch, the movements of the plungers must be the same so that the "pole" remains stationary. In our case, the lengths of the left and right sections of the shaping contour of the tightening punch relative to its "pole" are not the same. Therefore, the movement of one of the plungers is ahead of the movement of the other plunger by a certain amount. In this case, the movements are synchronized so that in the process of stretching the "pole" on the workpiece remains necessarily motionless.

In addition, when stretching the sheet blank using a horizontally located tension cylinder, the movement of its plunger with an inclined clamping plate in the installed state changes the angle of descent of the sheet blank relative to the tangent to the trailing edges of the tightening punch. To restore the position of the angle of departure of the sheet blank relative to the tangent, it is necessary to re-enable the table lift.

If the condition of synchronous operation of the left and right stretching cylinders to ensure the position of the "pole" stationary during modeling can be fulfilled, then to restore the position of the angle of departure of the workpiece relative to the tangent, we can implement the simulation of the process directly on the virtual press after installing the tightening punch on its table.

To analyze the results of the equivalent deformation and thickness in the process of shaping by a skinny, obtained in the process of modeling the first (left) and second (right) variants of the method, we
will place their pictures in an amount corresponding to the kinematic states of the press indicated on the cycle diagram, and the graphs of changes in thickness values in selected points of the sheet surface in figure 7.

Figure 7. Graphs of the distribution of the thickness of the sheet blank in the process of shaping by a tight-fitting for option 1 of the method (upper) and option 2 of the method (lower).

Let us transfer all visual attention to the graphs of the thickness distribution in the process of shaping by the skin, obtained in the process of modeling the first and second variants of the method (figure 7). According to figure 2, which shows the center line (red, including points B, E, H, K, N), the front line
(blue, including points A, D, G, J, M) and the back line (green, including points C, F, I, L, O). If in figure 7 the blue, red and green lines are bold, then these are points G, H and I. If the blue, red and green lines are of average thickness, then these are points D, E, F, I, K and L. If blue, red and the green lines are thin, drawn intermittently, then these are points A, B, C, M, N and O.

If you look closely at the graphs of the thickness distribution over the area of the finished part, where the division value between the digits of the ordinate is 0.005 mm, then the absolute difference in thickness of the part of the first version of the method is 0.016 mm and, accordingly, the second version is 0.013 mm, which is 18.5% better than the first option. This is due to the fact that deformations at the points on the central line B and N located at the edge of the end of the tightening punch in the first variant of the method could be localized, which increases the probability of sheet breaking. In the second variant of the method, plastic deformations are more stable, their greatest values are located in the middle part of the sheet blank. However, the method of implementing partial gripping of the edge part of the sheet blank, only by the extreme gripping devices, has never been used in practice.

The manifestation of the effect of stretching the outermost fibers of the workpiece (blue and green lines) indicates the presence of the effect of isometric bending of the shell surface after unloading the sheet blank at the third step motion, when the table was lowered, and the sheet continues to stretch up to 65 mm. The manifestation of the effect, when the sheet blank remained forcibly flat with rectilinearly arranged discrete clamping devices, provided a plastic configuration of the middle part of the sheet blank without localizing the thinning deformation and equalizing their values in different areas of the sheet.

3. Summary
In conclusion, we note that high requirements are imposed on the skins, especially in the quality of the surface of the skin parts, in the accuracy and shape of their external contours, obtained after shaping operations. At the same time, high requirements are imposed on the accuracy of the dimensions of the skins themselves and on the spread of the wall thickness of the parts. In addition, the designation of processing modes or the number of transitions during shaping by wrapping on the basis of reference data, even for well-known alloys, led to the appearance of a large number of rejects, which It was found that due to the significant non-uniformity of deformation when covering complex shells, the likelihood of defects associated with exceeding the permissible thinning of the sheet blank and the permissible grain size of the metal increased.

This led to an unjustified increase in the number of transitions due to unacceptable thinning and critical deformation of the recrystallization of the sheet material. “Critical” recrystallization is the main reason for the appearance of a coarse crystalline structure. This process is accompanied by intense grain growth as a result of heat treatment after cold deformation with critical degrees. For the annealed alloy D16, according to the reference data, the critical deformations are in the range of 10...12%, and for the material of the cladding layer of annealed cold-rolled aluminum AD0 - 4...6%. The number of transitions during the wrapping of the clad sheet material was determined from the last values.

The efforts of our research were aimed at the development of methods of shaping with a wrap, which reduce the degree of uneven deformation. It was necessary to minimize the thickness difference to the recommended limits, but for this a new technology was created to increase the degree of deformation during tightening, which is achieved practically in one transition without localizing the thinning deformation and equalizing their values in different areas of the sheet blank.

As a result of the studies performed, the conditions for symmetric wrapping were created and the trajectories of movement of the clamps of the sheet blank were modeled during the shaping of the blanket shells close in geometric shape to the skin, with a uniform change in thickness in different areas of the sheet blank without folds and breaks. This is only possible with programmed tying presses. For the transition to the level of adaptive program control, we propose to control the degree of deformation at characteristic points of the shell surface of double curvature due to the contactless measurement of deformations by the method of correlation of digital images.
The modern level of information technology makes it possible to create a digital twin of the press. You can create simulation models, promote them, create software that automates the process of building simulation models, i.e. develop this side of modeling.

References
[1] Bratukhin A G and Ivanov Yu L 1999 Modern technologies of aircraft construction (Moscow: Mechanical Engineering) pp 49-63
[2] Mikheev V A, Klochkov Yu S, Kuzina A A, Grechnikova A F and Savin D V 2012 The choice of the kinematic scheme of shaping by covering bypass-forming shells of complex spatial shape Vestnik of the Samara State Aerospace University 5(36) 239-45
[3] Mikheev V A, Grechnikov F V, Samokhvalov V P, Savin D V, Dementyev S G and Surudin S V 2014 Investigation of the kinematic diagram of sequential wrapping of biconvex shells on the FEKD wrapping press Vestnik of the Samara State Aerospace University 16 180-6
[4] Mikheev V A and Surudin S V 2017 Fundamentals of the calculation of the process of forming tight thin shells of double curvature Izvestia of Samara Scientific Center of the Russian Academy of Sciences 19(1-3) 555-62
[5] Mikheev V A, Dement’ev S G, Samokhvalov V P, Savin D V and Surudin S V 2013 Isometric conditions for the formation of a tight shell of double curvature with minimal thickness difference Izvestia of Samara Scientific Center of the Russian Academy of Sciences 15(6-1) 161-6
[6] Grechnikov F V 1998 Deformation of anisotropic materials (intensification reserves) (Moscow: Mashinostroenie)
[7] Grechnikov F V 2004 Optimal deformations during the shaping of double curvature shells with a covering Blank production in mechanical engineering (Moscow: Mechanical Engineering) pp 23-7