Computer application of the kinematics control system for a virtual stretch-tightening press RO-630-11

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Abstract. A computer application of the control system for the virtual display of a real stretch-tightening press RO-630-11, taking into account its kinematic features, has been developed. The focus is on the research carried out by the finite element method in modeling the processes of shaping a sheet blank by a tightening punch, with a surface oriented relative to the curvature lines and placed on the table of a virtual stretch-tightening press RO-630-11.

1. Introduction
The technological process of shaping by a wrap is organized to improve the quality of the aircraft skins by ensuring the geometric shape of the shell part, a more uniform workpiece thickness distribution after deformation and reducing the likelihood of its waviness and folds formation. To achieve these goals, it is necessary to control both the course of the technological process itself and the operation of technological equipment, i.e. manage its kinematics. Any management is based on the analysis of information about the technical condition of technological equipment. Obtained information is compared with the goals of management and, based on the results of comparison, a control action on the power bodies of technological equipment is formed.

During the modeling process, control actions that most effectively eliminate possible defects, property spread tolerances of the mechanical properties of the sheet blank are selected, and also a step that determines the number of finite element models is set. Control programs for sheet blank deformation are automatically generated for the obtained finite element models. In finite element models, there may be deformations falling into the dangerous areas of the forming limit diagram (FLD) [1, 2]. Initially, the first finite element model of the shaping process by a wrap is being developed, on the basis of which the basic part of the control program is formed. The resulting deformations from the first finite element model are superimposed on the FLD. Zones of the sheet blank, in which deformations fall into the dangerous regions of the FLD, must be monitored by an optical control system.

FLD are often used at the design stage of a technological process by means of its mathematical modeling. Thus, it is possible to analyze the manufacturing technology of the skin part and optimize the shaping process by wrap. This is possible only on a tight press with software control, which is the executive body of computer technology. Any technological process is performed in accordance with the algorithm and is a sequence of operations performed by mechanisms, including automatically. In practice, these are transitions between the states of technological equipment. The main source of obtaining information about the state of technological equipment is the control parameters measurement.
For this purpose, a computer application of the control system for a virtual display of a real stretch-tightening press RO-630-11, taking into account its kinematic features, was developed. The focus is on the research carried out by the finite element method in modeling the processes of shaping a sheet blank by a tightening punch, with a surface oriented relative to the curvature lines and placed on the table of a virtual stretch-tightening press RO-630-11. The main goal of modeling the process of forming tight shells of double curvature is to select the technological mode of shaping the sheet with minimizing rejection and maximizing the degree of shaping at an acceptable level of thinning sheet blank. Simulation of the process by the finite element method is carried out on a tightening punch, with a surface oriented relative to the curvature lines and placed on the table of a virtual stretch-tightening press, which leads to symmetry during shaping by a wrap [3, 4]. In LS-DYNA the modeling of sheet material in the process of its shaping with a wrap became reliable after the introduction of a number of special algorithms [5].

2. Principles of computer application development of the press kinematics control system

The development of a computer application is based on three main principles:

1) expanding the constraints imposed on current studies by currently available finite element methods that take into account simplified equipment kinematics;
2) modeling optimization process, which allows to obtain new methods of shaping by a wrap and at the next stage will include analysis using simulation modeling to control the kinematics of a stretch-tightening press RO-630-11 based on a digital twin;
3) the digital representation of the control object will lead to the need for using the existing developments in the field of storing information, operating with it and applying it in various fields, as well as technological independence from imported software.

The computer application of the press kinematics control system consists of a simplified three-dimensional model of the equipment and a graphical user interface designed to control the kinematic movements performed by the working bodies of the press, which makes it possible to accurately simulate its real kinematics (figures 1 and 2). In addition to this, the interface includes the control and positioning of each working body of the stretch-tightening press figure 3).

![Figure 1. Virtual model and user interface of stretch-tightening press RO-630-11.](image-url)
Figure 2. Graphical user interface (Create and control RO-630-11).

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 discrete clamping devices. The longitudinal axis of tension coincides with the textural symmetry axis of sheet blank properties and is located in the direction of the longitudinal curvature of the tightening punch surface.

The highlighted «thick black» arrows in figure 3 correspond to the main movements of the working bodies of the stretch-tightening press (stretching 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 press RO-630-11 (figure 4).
Figure 4. The main working bodies of the stretch-tightening press: stretching cylinders 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 rotation cylinders of the clamping plate of the press RO-630-11.

As a result, it will be possible to customize the animation of the working bodies movements for a specific shaping process. This animation will be automatically decoded in a configuration language that can be understood by software that provides finite element modeling. Using animation, the method optimizes the configuration for calculation and will significantly increase the number of movements calculated and evaluated in this study. At the stage of calculations, the operator-technologist personally checks the calculation results and evaluates possible adjustments that need to be made to the animation in question in order to send a new animation into the calculation, comparing the current results.

Thus, the monotony of deformation will be ensured, the shaping of the sheet blank must be carried out under symmetrical tightening conditions without its localization in the part of the sheet blank located between the edge of the tightening punch and the clamping jaws of the press. The stretching of a sheet blank during shaping by a wrap differs not only in the magnitude of the forces, but also in the area of their application along the edge of the blank. The border movement directions of the plastic deformation zone can be changed by moving the line of the sheet blank clamps along a certain trajectory.

To do this, it is necessary to programmatically coordinate the nature of the working bodies movement of stretch-tightening press. The kinematic grounded schemes for shaping the shell of the considered geometric shape by a wrap 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 nature of the plastic deformation zone either in a straight position or in a curvilinear position of discrete clamps.

Then, at the next stage, it is planned to expand the computer application to include an automated analysis of the results using a computer, which will change the animation configuration of the equipment under consideration and, having corrected some of its parameters, will re-send it for calculation. With the introduction of such a stage, it will become possible to evaluate dozens of options for the movement of the kinematics of the stretch-tightening press instead of several possibilities which are now estimated by current methods, mainly manual. This realized potential will take us into the new technological reality of the digital twin.

Computer study of the tightening punch for the implementation of the symmetric tight-fitting conditions will make it possible to quickly perform complex calculations of the parameters of the skin-forming processes even without the use of the traditional finite element method, which is characterized by the duration of the calculations and a relatively high probability of error. However, the achievements of modern information technologies that increase the level of production and non-production
technologies based on the digital twin – the digital representation of the object, have already led to the need to use the existing developments in the field of information storage, operate with the calculation results and use them in optimizing the control algorithm.

These are serious technological advances, because they accumulate the latest developments in the field of computing technology, in the storage and use of information. Therefore, today it is not difficult to combine together the results of calculations carried out using various mathematical tools, for example, an analytical model of calculated data and a numerical model using the finite element method. As the information accumulates, it is possible to predict, on the basis of the basic digital model (simulation model), the direction of control algorithm optimization, providing visualization of the deformation zone development on the surface of the sheet blank, setting up the animation of the movements of the working bodies for a specific shaping process by the skin using a computer application of the control system for the kinematics of the virtual stretch-tightening press RO-630-11.

The digital twin is the bridge between physical and digital reality. Software components and physical processes are closely related and affect each other. First of all, these are sensors that collect information about the operation and condition of equipment and, together with a simulation model, are an excellent training simulator, combining an analytical model with a physical model that will train operators. The effectiveness of the creation, use and development of digital twins technology is due to the quality of the simulation model construction. This computer application of the control system is provided by the workstation of the technologist. Currently, the computer application depends only on software that performs the finite element analysis. To eliminate this drawback, it is necessary to use the system interface, which is currently developed for work within the software in the LS-DYNA software package as its preprocessor for preparing the calculation by the finite element method.

The computer application of the control system can be developed into a completely autonomous version and will allow to obtain a realistic representation of the shaping processes by the wrap with a full-fledged 3D-visualization of all working bodies movements of stretch-tightening press RO-630-11.

3. Advantages of using a computer application of the press kinematics control system

The computer application of the control system allows, among other things, to take into account:

• real kinematics of the considered equipment;
• various models of the material – elastic, plastic, visco-plastic and taking into account hardening;
• friction and contact between the tightening punch and the molded skin parts;
• self-contact in the forming part to predict the formation of folds.

The computer application, after completion and commissioning, can be reformatted for a different hardware control system. This is due to the fact that the computer application contains a core that includes the basic functionality necessary for modeling the shaping processes by the wrap (graphical user interface, solver, material base, finite element meshing tools, and some others). Traditionally, this core will be supplied with elements of the graphical interface focused on the computational models preparation of the shaping processes with a wrap on one or another equipment.

The uniqueness of the approach when creating a computer application lies in the fact that two methods are used: the finite element method and the FLD of sheet material, which allow realistically calculating defects typical for metals, such as folding, tearing and unacceptable thinning of sheet material. The ability to specify a variety of kinematic conditions, local coordinate systems, various kinematic connections allows to consider and accurately describe the kinematic features of the used equipment.

Other software packages often require expert knowledge to prepare complex models. A computer application is targeted at specialists in technology departments, such as a process engineer or engineer for the development of production processes. These users generally do not have to deal with mathematical theories and may not be experts in computer modeling. The graphical user interface is
lightweight and easy to learn, reducing training time. The user can focus on the wrap shaping process itself, rather than having to face the hassle of customizing how the software works.

All envisaged shaping processes can be easily simulated with a few clicks of a computer mouse. However, there are no restrictions for users with only basic training. Experienced users can work with the advanced functionality of the package, which makes it possible to simulate the processes of forming parts of any complexity.

Key features of a practice-oriented graphical user interface:

- simple and intuitively clear graphical user interface with work in Windows style (with drag & drop technology);
- all modeling capabilities are available in a single environment (3D-representation, model preparation, calculation and processing of results);
- lightweight and easy to learn package;
- the terminology of specialists of technological departments is used;
- clear division into object area (tools, machines, materials, etc.), process area (forming operations) and graphics/results visualization area;
- all objects can be made available in the database;
- technology for working with templates.

These characteristics simplify the choice of the method of shaping the wrapped part by moving the line of sheet blank clamps along a certain trajectory determined by the cycle diagram of the step the main and auxiliary working cylinders of the stretching press movements. Figure 5 shows the cyclic diagram of the step movements of the main and auxiliary working cylinders of the stretch-tightening press RO-630-11 (figure 4), where the indices of the kinematic state of the press and the conventional calculation time are shown in circles.

![Cyclic diagram of the step movements of the main and auxiliary working cylinders of the stretch-tightening press RO-630-11](figure5.png)

**Figure 5.** Cyclic diagram of the step main and auxiliary working cylinders of the stretch-tightening press RO-630-11 movements.

The cycle diagram does not show the initial installation of the blank into straight-line discrete clamping devices. Other default settings are present in the cycle diagram and they 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» touch 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 considered method provides a minimum level of thickness variation of the simulated shell. However, matrices of press control parameters were pre-formed in the form of animation. At the stage of calculations, we personally checked the calculation results and evaluated possible adjustments that had to be made to the animation in question in order to send a new animation into the calculation, comparing the current results. This work was carried out using a computer application of the control system on the graphical user interface (Create and control RO-630-11), where there are «windows» on the left and right (figure 2), which show:

- the displacement values of the extension cylinders and there are «sliders» that set these values in mm under the name «Rastysayeniye», the horizontal extension cylinder of the left base will be LB01, the horizontal extension cylinder of the right base will be PB01;
- the displacement values of the hydraulic cylinders for turning the clamping plate and there are «sliders» setting these values in mm under the name «Plita», the hydraulic cylinders for turning the clamping plate of the left base will be LB02, the hydraulic cylinder for turning the clamping plate of the right base will be PB02.

The angle of rotation of the clamping plate in degrees was fixed and its value was taken out in a separate «window» on the left and right of the graphical interface. Due to the peculiarities of the stretch-tightening press RO-630-11 kinematics, during the operation of the horizontal hydraulic cylinder for stretching and turning the power lever of the kinematics of the clamping plate movement, the given angle, which determines the descent of the sheet blank from the stretching punch tangentially into the press clamps, is constantly changing. To restore its tangential descent, a corrective rotation account of the kinematics power lever and a corrective lift of the press table are required. In the process of modeling, under the control of the virtual stretch-tightening press RO-630-11 kinematics, the contact of the drawing punch surface was visually maintained in the area of the sheet blank descent by introducing a corrective lifting of the press table. These movements are available in the cycle diagram of step movements in figure 5 and we will highlight them below in the line of this step: the displacement values of the hydraulic cylinders for installing discrete clamps along the contour and there are «sliders» setting these values in mm under the name «Perediye zazhimy» and «Zadnye zazhimy», hydraulic cylinders for installing discrete clamps along the contour of the left base will be LB03 and LB04, hydraulic cylinders for installing discrete clamps on the contour of the right base will be PB03 and PB04.

The angles of discrete clamps installation rotation along the contour in degrees were fixed and their values were taken out into a separate «window» on the left and right of the graphical interface. Similarly to the previous case, in the process of modeling under the control of the stretch-tightening press RO-630-11 kinematics, the contact of the tightening punch surface with the sheet blank in the corner zones was visually maintained. On the graphical interface in its central part there are «windows» that show the movements of the hydraulic cylinders for lifting the press table and there are «sliders» that set these values in mm under the name «Tsilindr 1», «Tsilindr 2», «Tsilindr 3» and «Tsilindr 4». The controlled coordinates are the left and right extreme hydraulic cylinders: «Tsilindr 1» with the designation STO1 and «Tsilindr 4» with the designation STO4 in figure 2.

To simulate the shaping process by a wrap using a computer application of the virtual stretch-tightening press RO-630-11 kinematics control system, several variants of kinematic shaping methods can be simultaneously considered, which make it possible to minimize the difference in thickness of the simulated shell to the analyzed limits. In addition to this, the graphical interface includes control and positioning of each working body of the virtual press. At the same time, management is the formation of such an process organization that ensures a given nature of its course. In other words, management is a sequence of actions that should be taken to achieve a specified goal.
First you need to develop an action plan, then write it down (the result of the recording will be an algorithm) and execute. The result of the execution is the operations sequence of the technological process. If the technological process is carried out by the operator, then it understands how to ensure the execution of the actions sequence provided by the algorithm. To perform these actions, the machine needs to ensure that it understands the algorithm as a sequence of commands leading to the achievement of the goal. It is enough for the operator to see the algorithm in verbal or graphic form in order to implement the technological process. The machine cannot see the algorithm. Even if it is written in an algorithmic language, the machine cannot read its commands.

Consequently, in the case of machine execution of an algorithm, there must be some kind of intermediary between it and the technological process, which will ensure the machine's understanding of the algorithm instructions. In other words, you need a translator who can transform commands into actions that will force it to perform the necessary actions in accordance with the algorithm. The functionality to be performed by this translator is called a control device.

4. Summary
The computer application of the kinematics control system for a virtual stretch-tightening press RO-630-11 is necessary for implementation of the calculated control algorithm and the results of shaping processes optimization by the wrap, adapted to real production conditions with control of the process itself parameters. The computational control algorithm and the optimization results are formed on the basis of the operator's workstation using a computer application of the kinematics control system for a virtual stretch-tightening press RO-630-11. In addition, the computer application of the control system for the stretch-tightening press RO-630-11 automation will help to solve the following tasks:

1. Interaction with the operator through an automated workstation based on the user's personal computer; a touch-sensitive local panel and a push-button post located in close proximity to the press; light and sound indication.
2. Formation of control signals to the hydraulic power drives of the press according to the calculated control algorithm.
3. Collection and processing of signals from sensors installed on press drives and vision cameras.
4. Manual and automatic movement of the table cylinders and extension cylinders until the required deformation of the sheet blank is achieved.
5. Control, indication and recording of process parameters such as:
   - positions and speeds of the press main hydraulic cylinders;
   - efforts created by the main hydraulic cylinders of the press;
   - the values of the sheet blank deformations obtained from the object by the computer vision device.
6. Formation of data on the results of work and their recording in the ROM-system.

The computer application of the kinematics control system for a virtual stretch-tightening press RO-630-11 solves the problem of centralized automated control of the technological process, interacting with all other parts of the software and hardware complex. This application exchanges information with lower-level devices via the OPC server. The OPC server is free software. It is intended for organizing interaction between software and connected equipment using typical industrial protocols, for example, Modbus TCP.

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