Introduction of oblique sections into the curves web in modeling the framing of a vessel hull in KOMPAS-3D

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Abstract: The paper considers the issues of solving the applied problem of three-dimensional modeling of a vessel hull theoretical surface in KOMPAS-3D computer-aided design system. The methods to increase the smoothness of skeleton curves – frames – are shown. Various methods of modeling the vessel hull as a frame surface are considered: a surface in sections and a web of curves. Their comparative analysis was carried out from the point of view of surface accuracy and smoothness according to the set of proposed quantitative parameters to assess the modeling quality of a frame surface. The method to improve the modeling quality is proposed through the introduction of additional sections with oblique planes – ribbands – into the curves web. Various methods of 3D modeling of the vessel hull were put into practice, as well as the comparative results of quantitative study of the modeling quality of the vessel hull by various methods are given. It was shown that additional oblique sections introduced into the curves web may improve the quality of the frame surface. The results of the study may be of practical interest in modeling and evaluating the quality of a wide class of frame surfaces defined by more than one set of sections.

1. Introduction

Stated geometrically, the hull of a vessel is a body bounded by a complex curved surface. In terms of its complexity, such a surface cannot be described analytically; therefore, the so-called plan of lines (PL) is used to define the surface of a vessel, which depicts a set of sections of a molded surface with planes parallel to the molded base of projections. In fact, the hull PL represents a mesh frame. Frame surfaces have a number of positive qualities determining their extensive use in geometric modeling. The disadvantage of frame surfaces is that the points that do not lie on the frame lines cannot be uniquely defined and their position in space will only depend on the algorithms for constructing and smoothing the resulting surface. Therefore, different surface shapes may be constructed on the same frame, and the method of surface forming between sections plays a crucial role in achieving the desired shape of the frame surface. At the same time, the accuracy and smoothness of the frame surface will be bound to the accuracy and smoothness of lines of the original frame, as well as to the total number of lines determining this frame. The thicker the frame lines are located, the more precise are the surfaces, but it will be more difficult to ensure the smoothness of the surface. In addition to curved frames, i.e. one set of lines, mesh frames formed by two or three curve line sets are used [1].
2. Initial data and purpose of the study
The initial data for the study included a bitmap image of a plan of lines of a container ship with a full image of a “hull”, deck lines and the main lines.

The purpose of this study was to show the practical solution to the problem of geometric modeling and the study of complex frame surfaces using a universal medium-level CAD KOMPAS. As indicated earlier, CAD KOMPAS-3D has the greatest possibilities for modeling surfaces of high complexity in mechanical engineering when designing the models of mechanisms and machines [2], so we were interested in the applicability of this CAD in shipbuilding. The purpose of this study was to consider the various methods of constructing a frame surface provided for in CAD KOMPAS and to develop a methodology for comparative analysis of modeled surfaces according to a number of quantitative indicators that would uniquely characterize the quality of the surface.

3. State-of-the-art and relevance of the study
The analysis of open sources showed that shipbuilding CADs are currently used to solve the problems of modeling the surface of a ship’s hull. Their functionality and application examples are quite widely covered in accessible sources, for example, in [3, 4]. According to the analysis of available data, we believe that the most famous are such “heavy” CADs as Foran [5] and CATIA [6]. At the same time, the problems of geometric modeling of shipbuilding objects in universal CAD systems, such as KOMPAS-3D, are not sufficiently described. The few available sources on this topic show only some examples of KOMPAS-3D applications in solving a limited range of problems of geometric modeling of the hull by creating a frame surface [7, 8]. There are also examples of the use of analytical models to describe part of the vessel’s lines [9], which, in our opinion, have no practical prospects due to their needless complexity. Moreover, the studied open sources do not contain examples of a quantitative study of the three-dimensional model of the vessel’s hull in terms of its smoothness and accuracy. Therefore, we consider it urgent to analyze various methods of modeling the ship’s surface in CAD KOMPAS and to develop a method for determining the quantitative characteristics of the quality of the modeled frame surface in order to evaluate its smoothness and accuracy.

4. Methods to ensure the frame curves smoothness
Since the given PL was a bitmap image, we first needed to transfer it into a vector image. The Bezier curve was used to construct the specified lines of the vessel, since its nodes lie directly on the curve.

We used frame lines as frame sections, so their shape is decisive. We propose to set two indicators as modeling criteria: accuracy and smoothness. In this regard, the main requirements for the lines of frames will be their accuracy and smoothness. Besides, the obtained three-dimensional models of the vessel’s hull will be studied in terms of these characteristics.

The smoothness of the frame curve may be partially achieved using the Bezier curve since the principle of constructing this curve implies the continuity and smoothness of the approximation line passing through given points (nodes). A node is considered smooth if the incoming and outgoing tangents in that node lie on the same line [10]. In the general case, the degree of smoothness refers to the number of coinciding derivatives of complementary curves at junction points [10]. In other words, if the second derivatives coincide at the node, then the second degree of smoothness of the curve is indicated. Thus, when constructing the Bezier curve in KOMPAS-3D only the first order of smoothness in nodes is initially provided. However, for subsequent modeling of a smooth surface, in which these curves will act as a frame, the first order of smoothness of the nodes of the original curve may not be enough. In other words, even in the first order of smoothness the curve is smooth in the mathematical sense; however, it will not be smooth geometrically. Here we need to introduce the concept of geometric smoothness – a continuous change in the tangent vector along the curve. In geometric modeling, the concept of the fairness of lines associated with geometric smoothness and characterizing the degree of smoothness of a curve is more applicable. With regard to geometric modeling, the smoothness of the curve will mean a monotonic change in the curvature along the
curve [11]. Therefore, instead of the degree of smoothness of the curve, it will be more convenient to use the concept of the fairness of lines.

It is possible to increase the smoothness of the Bezier curve in the following ways:

• by changing the position of curve nodes;
• by changing the length of the tangent vector in the node;
• by changing the direction of the tangent vector in the node;
• by adding or removing nodes.

Since the position of the nodes of the Bezier curve is strictly fixed, when determining the shape of the frame, it is only possible to increase the smoothness of the curve in the last three ways.

Thus, Figure 1a shows a first order smoothness node, while the second derivative in the node changes step-wise, i.e. the lengths of the incoming and outgoing tangent vectors differ dramatically from each other. This explains the visual disturbance of the line at this node. To increase smoothness, tangent lengths must be as close as possible to each other. If the values of the tangents and their inclination angles to the curve are equal, then we can talk about reaching the second order of smoothness in the node, and this node will be symmetrical. In other words, the value of the first derivative and the second derivative does not change at the junction point of segments. The result of this editing is shown in Figure 1b.

![Figure 1](image)

**Figure 1.** Increase of smoothness by changing the length of the tangent vector in the node: a) node of the first order of smoothness; b) node of the second order smoothness (symmetrical node)

Accuracy is ensured by the maximum justified number of nodes defining the lines, and its smoothness – by using the methods described above.

Following the procedure described above, we obtained predetermined lines of frames and lines of the vessel with a sufficient level of smoothness. In the future, to check the quality of the modeled surface, we will also need specified waterlines and buttocks. These lines were built by projection methods along the frames and the PL mesh, and thus a full PL was built with all the specified lines determining the shape of the vessel’s hull.

5. Modeling and study of the vessel surface by various methods

The first basic version of the ship’s hull surface was made in sections, where these frames copied from a given plan of lines to the corresponding parallel offset planes, were used as formlining sections. The resulting set of sections forming the curved frame of the modeled surface by sections is shown in Figure 2a. Figure 2b shows the resulting surface by sections.
To assess the smoothness and accuracy of the frame surface, we propose using the so-called reference sections of the vessel surface with the same planes giving the shape of waterlines and buttocks in the PL. In this case, the choice of the position of the cutting planes of the reference sections is caused by the presence of given lines of intersection of the vessel surface by these planes. Using such reference sections, which do not coincide with the frame sections, it is possible to understand the behavior of the surface between sections, which allows evaluating not only the smoothness of the obtained surface, but also the accuracy of its modeling, since the planes of the specified waterlines and buttocks were taken as cutting planes for the reference sections. In case of hypothetical ideal modeling accuracy, it should be expected that the curves coincide completely with the reference sections and the corresponding specified lines of the vessel.

The shape of reference waterlines and buttocks makes it possible to preliminary evaluate the obtained surface and conclude that the surface constructed by sections has sufficient smoothness, but does not provide the given shape of the bow and afterbody (Figure 3), as well as the deck line. At the same time, the largest deviations from the given lines are observed in the area of the extremities of the bow and afterbody.

It can be assumed that the introduction of intermediate sections – additional frames in the most problematic areas, may ensure the required quality of the ship’s surface. However, as we showed in work [12], the addition of certain intermediate frames to the main frame results only in a local increase in accuracy, but at the same time significantly impairs the smoothness of the entire frame. As shown in Figure 3, the surface by sections clearly does not satisfy the desired modeling quality.
Figure 3. Deviation from the specified shape of the main line for the surface by sections

One way to better describe the behavior of a frame surface between the initial sections is to add an additional set of curves to the frame. Surfaces based on two sets of curves are sometimes called frame-kinematic, since the curves of the second set, in fact, determine the law of changing the curves of the first set. Such surfaces provide greater control over the shape of the created surface.

CAD KOMPAS-3D offers a possibility of modeling surfaces by the web of curves of two directions. It would be logical to propose the specified waterlines as second direction curves, while the frames will remain the curves of the first direction. However, there are some retention requirements to the web of curves in KOMPAS-3D. Thus, each curve of one direction must have one common point with each curve of the other direction. This requirement cannot be fulfilled due to the peculiarity of the shape of the hull: initial and final frames do not intersect with lower waterlines. Due to this circumstance, we propose to use the main line and a deck line as curves of the second direction from the lines available in the given plan of lines. Only these lines on a given PL meet all the requirements of the “web of curves” operation. In the process of modeling, the line of the bow and afterbody was created as a flat Bezier curve, the node points of which necessarily belonged to the lower middle points of each frame (Figure 4a). To ensure a given shape of this line, additional nodes on the Bezier curve were added at the locations where curvature changes most. A predetermined shape of the main line of the vessel was achieved by moving the intermediate nodes. At the same time, the deck line was constructed as a spatial curve using the “Spline 3D” operation, the vertices of which were the endpoints of each frame. In this case, based on the requirements of the system the curves of the second direction intersect at the points of the bow and afterbody ends indicated as the extreme points of the first set of curves. A prerequisite for successful modeling of a surface through a web of curves is the presence of a web of node points as the intersection points of curves of both directions.
Figure 4. a) fragment of a web of bow curves; b) surface along a web of curves

Thus, a model of the vessel’s hull was built along a web of curves, which is shown in Figure 4b. To compare its smoothness and accuracy with the model, reference sections were also obtained for all waterlines and buttocks, the deck line and the main line of the ship. As a result of a preliminary analysis of the shape of the sections and comparison of the deck lines and the lines of the vessel with the specified lines on the PL, it can be concluded that a surface built along a web of curves may ensure the shape of the bow and afterbody required by the main lines of the vessel, as well as the deck line, but in these areas there is a decrease in surface smoothness.

6. Introduction of oblique sections – ribbands – into a web of curves

In shipbuilding, in order to obtain greater accuracy when setting the shape of ship lines, in addition to the above three types of sections (frames, buttocks and waterlines), the hull surface is made with longitudinal and transverse planes, the surface sections are made with planes inclined to the longitudinal plane and perpendicular to the plane of the midship frame. The lines of intersection of the ship’s surface with such oblique planes are called ribbands. On the “hull” projection, the ribbands are projected in the form of oblique lines (Figure 5a), and on the “side” and “half-breadth” projections – in the form of curves showing the actual shape of the ribband, for which the ribband planes are rotated relative to the line of their intersection with the longitudinal plane until they are aligned with the latter or to the position parallel to the main plane. Figure 5 shows the construction of two ribbands: at an angle of 15 and 30 degrees from the longitudinal plane. The splines that define the ribbands were built at the intersection points of all frames with the corresponding oblique planes passing through the extreme bow point.
Figure 5. Oblique sections of the ribband surface: a) on the “Hull” projection; b) on the “Side” projection

Figure 6 shows a fragment of the bow built along a web of curves, where two additional lines – ribbands – were also included in a family of second-direction curves in addition to the deck and bow lines.

Figure 6. Surface fragment along a web of curves with ribbands

7. Quantitative evaluation of the quality of frame surfaces by the reference section method

The smoothness and accuracy of modeled surfaces may be uniquely estimated by the smoothness and accuracy of the reference sections, in our case – waterlines and buttocks obtained from models in comparison with those given on PL. We accept the assumption that the PL lines were initially designed quite smoothly and therefore may be used as a model pattern to compare this indicator. To quantify the smoothness and accuracy of constructed surfaces, we propose to use the following indicators of reference sections (Figure 7):

- maximum linear deviation from the specified line: \( \Delta_{\text{max}} \);
- integral modeling error on \( i \) line – total area limited between the control and the specified line: \( S_{\text{li}} = S_1 + S_2 \), where \( S_1 \) – sum of all areas on the one side of the specified \( i \) line, \( S_2 \) – sum of all areas on the other side of this line;
- relative integral error of modeling on \( i \) line: \( S_{\text{rel}} = (S_{\text{li}}/S_{\text{ti}})*100\% \), where \( S_{\text{ti}} \) – total area under the curve of \( i \) line;
- offset of a reference section from the specified line: \( \delta = |S_1 - S_2| \);
The excess number of points of intersection of the obtained and specified line: \( \Delta N_i = N_{tot} - N_i \), where \( N_{tot} \) – total number of points of intersection of the reference and specified curve of the line, \( N_i \) – number of nodes of the Bezier curve that specify this line.

The maximum linear deviation from the given line \( \Delta_{max} \) may be an absolute indicator of the accuracy of the line reproduction and an indirect indicator of smoothness. As an integral estimate of accuracy, we propose to consider the total area of the figure limited by the reference and specified line – \( S_l \). This indicator is useful for assessing the accuracy of the entire line along its entire length and in comparison with other lines of the same set of sections, i.e. separately waterlines or buttocks. Whereas in order to compare the accuracy of modeling of different types of lines with each other, we introduced such an indicator as the relative integral error of modeling, i.e. the share of the erroneous area to the total area under the line curves (\( S_{rel} \)). The introduction of a relative assessment was caused by the incorrect comparison of smaller frames with longer waterlines and buttocks only in the erroneous area \( S_{li} \). It is proposed to use a module of area difference from different sides of the given curve to estimate the presence and value of deviation of the reference section to one or the other side from the specified line. This deviation will be significant when the area on one side of the specified line (\( S_1 \)) is significantly different from the area on the other side (\( S_2 \)). The hypothetical situation where the whole reference section line will lie on one side of the specified line, i.e. one of the areas is zero, is impossible, since there must be points of intersection of the reference section with the frame curves – specified frames (\( N_f \)). At the same time, the total number of points of intersection of the reference and specified lines (\( N_{tot} \)) cannot be less than the number of ship lines with which this line intersects in the plan of lines (black circles in Figure 7). However, the number \( N_{tot} \) itself cannot objectively show the smoothness of the curve, since different lines intersect with a different number of frame lines, for example, lower waterlines. Given this circumstance, only the difference \( N_{tot} \) and \( N_f \) may be an indirect measure of smoothness of the reference section curve. The larger it is, the more often the reference section line intersects with the specified line, which means that there will be more inflections on the curve, which is undesirable, since it sharply reduces its smoothness.

![Figure 7. Quantitative indicators of accuracy and smoothness of reference sections](image-url)

The above indicators allow objectively and quantitatively evaluating the accuracy when modeling a frame surface in KOMPAS-3D, and then the minimization of these parameters may be considered an objective function of geometric modeling.

Quantitative quality indicators of the obtained models were determined using the method proposed by the authors using standard CAD KOMPAS operations. For the purpose of a comprehensive quantitative evaluation of the analyzed surfaces, the arithmetic mean for all lines of a given surface type was determined for each indicator. It should be noted that the numerical values of maximum
deviations and areas were measured without taking into account the scale of the plan of lines and are only relative in nature for comparison.

8. Results and Discussion
The study resulted in the method of integrated quantitative assessment of the quality of modeled frame surface of the vessel according to a number of numerical indicators. Three ship hull surfaces were built in various ways on the basis of the given PL and a comparative study of the obtained surfaces was carried out: by sections (frames), by a web of curves without ribbands and by a web of curves with ribbands thus determining all complex parameters of modeling quality for each surface. The numerical results of the study are shown in Table 1.

| Surface building method                        | Complex surface quality indicators |
|------------------------------------------------|-----------------------------------|
| By sections                                     | Δmax | S1     | Srel, % | ΔN  | δ = | | S1 - S2 | |
| By a web of curves without ribbands             | 6.35  | 88.43  | 0.762   | 0.25 | 53.61 |
| By a web of curves with ribbands                | 2.82  | 29.01  | 0.128   | 0.5  | 4.92  |
|                                                | 1.49  | 10.37  | 0.094   | 0.38 | 3.79  |

The results of this study make it possible to draw the following conclusions. The frames set at PL are not sufficient to model a surface ensuring sufficient accuracy. A surface constructed by frames only, although having the best smoothness according to ΔN of the three surfaces under study, shows a significant modeling error, i.e. low accuracy. Besides, there is a strong displacement of reference lines in one direction in this surface. The second surface built by a web of curves shows a significantly smaller modeling error in areas and linear deviations and may ensure the shape of the bow and afterbody required by the main lines of the vessel, as well as the deck line, since these lines are included in the frame. However, this surface has a lower smoothness index. The third surface built by a web of curves with ribbands showed a varying degree of improvement in surface quality concerning all indicators.

9. Conclusion
The method of assessing the surface quality proposed by the authors is convenient, since it is based on the standard functionality of CAD KOMPAS and may objectively show the result of modeling the frame surface with regard to its quality. This method of surface testing by reference sections may be used for any other frame surface provided there are several sets of specified frame lines. In this case, one of the sets of sections is used to build a frame surface, and the other sets are used to check the quality of this surface. This method is even more convenient since it allows obtaining an objective idea of the behavior of the frame surface between sections. We also showed that the surface quality of the hull may be improved by adding additional oblique sections.

References
[1] Nartova L G, Yakunin M 2010 Descriptive geometry: textbook. manual for students of technical sciences university specialties (Moscow: Akademiya)
[2] Klimenko E S, Borodina L N, Rychenkova A Yu 2018 Applied use of computer-aided design systems for modeling mechanisms and machines in marine transport Bulletin of VSAWT 57 38-44
[3] Abdulin A Ya, Senyushkin N S, Suxanov A V, Yamaliev R R 2010 Computer aided design systems as a tool for solving science-intensive design problems in shipbuilding Bulletin of the Voronezh State Technical University 10 56-63

[4] Bubnov A 2000 Computer-aided design systems in shipbuilding CAD and graphics 5 24-29

[5] LIN R et al. 2011 Application of the Foran software on the engineer design [J] Machinery 8 8

[6] Dong-mei C K Z, Rui-xi W U 2008 Elementary introduction of CATIA software's application on shipbuilding Journal of Qingdao Ocean Shipping Mariners College 4

[7] Dmitriev S A 2015 Creating a theoretical drawing of the ship's hull using the KOMPAS CAD system (SPb.: SPBGMTU)

[8] Goravneva T, Semenova-Tyan-Shanskaya V 2019 Ship hull modeling in KOMPAS 3D CAD CAD and graphics 4 42-46

[9] Pecz N G 2018 Analytical three-dimensional model of the bow end of ice vessels and icebreakers Bulletin of the engineering school of the Far Eastern Federal University 4 37

[10] Baturina E V, Plonskij P L 2006 Curve modeling in modern computer-aided design systems Bulletin of irkutsk State University 4 28

[11] Golovanov N N 2002 Geometric modeling (Moscow: Izdatelstvo fizikomatematicheskoj literatury)

[12] Rychenkova A Yu, Klimenko E S, Borodina L N 2020 Geometric modeling and assessment of the quality of the hull frame surface in KOMPAS-3d CAD Russian journal of water transport 62 82-91