THE PRODUCT DESIGN PROCESS USING STYLISTIC SURFACES

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ABSTRACT

The increasing consumer requirements for the way what everyday use products look like, forces manufacturers to put more emphasis on product design. Constructors, apart from the functional aspects of the parts created, are forced to pay attention to the aesthetic aspects. Software for designing A-class surfaces is very helpful in this case. Extensive quality analysis modules facilitate the work and allow getting models with specific visual features. The authors present a design process of the product using stylistic surfaces based on the front panel of the moped casing. In addition, methods of analysis of the design surface and product technology are presented.

KEYWORDS: stylistic surface, Catia V5, Alias Auto Studio, CAD model

PROCES PROJEKTOWANIA WYROBÓW Z WYKORZYSTANIEM POWIERZCHNI STYLISTYCZNYCH

STRESZCZENIE

Stale rosnące wymagania konsumentów co do designu kupowanych wyrobów zmuszają producentów do położenia większego nacisku na stylistykę produktów. Konstruktorzy oprócz aspektów funkcjonalnych tworzonych części zmuszeni są do zwracania uwagi na aspekty estetyczne. Pomocne staje się oprogramowania do projektowania powierzchni A – klasy. Rozbudowane moduły do analizy jakości znacznie ułatwiają pracę i pozwalają uzyskać modele o określonych cechach wizualnych. Autorzy przedstawiają sposób projektowania wyrobu z wykorzystaniem powierzchni stylistycznej na podstawie przedniego panelu obudowy motoroweru. Ponadto zaprezentowano metody analizy powierzchni designerskiej oraz technologiczności wyrobu.

SŁOWA KLUCZOWE: powierzchnia stylistyczna, Catia V5, Alias Auto Studio, CAD model

1. Introduction

The problem of recording the engineering structure has existed since the first, ancient engineers had to systematise and pass on their knowledge. In ancient times the carriers of various information, including those from engineering, were clay tablets. Later, paper was used for this purpose. Such a way of recording the construction was a rather tedious and laborious process. It was also difficult to duplicate designed constructions. It was not possible to use once prepared, standardised or repetitive parts in several projects. Examples of such details may be bolts or nuts.

In the beginning of computer design, the work on computerised control of machine tools was commenced in the 1950s. Initially, the work focused on reflecting the geometric form of the machined part in the APT programming language. In 1963 I. Sutherland, a MIT doctoral student, developed the SKETCHPAD system, which allowed the computer to display graphical information. This moment is considered to be the beginning of computer-generated construction documentation [1]. The second half of the twentieth century and the beginning of the 21st century brought rapid development of computer techniques. The computerised design of CAD (Computer Aided Design) became standard nowadays [2].

Integration of systems from the environment to the procurement of product quality control orders is called PLM (Product Lifecycle Management). This is the basis for introducing various strategies and concepts of production (e.g. Just in Time, Virtual Factory, etc.) [3].

2. Product project in CAD systems

There are different ways of modelling products in CAD systems. The most basic is solid modelling. This modelling procedure consists in creating three dimensional models by drawing or rotating a previously designed contour. In subsequent steps Boolean operations are used to add or subtract other bodies obtained in a similar manner. In such a model holes, chamfers and rounds can be easily made. This is the easiest way to make 3D models. It is mainly used in the design of roller-type products or discs where only functional properties are important [4]. This is often done by reinforcing structures -- ribs for models designed on the surfaces.
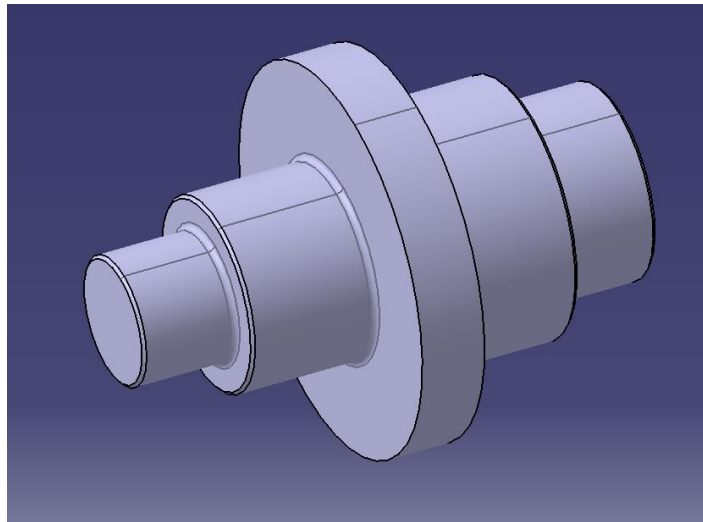

Fig. 1. Solid body made in 3D software (own study)

Surface modelling places significant emphasis on the stylistic side of the model. This type of design allows for shaping geometrically more sophisticated products. Current market conditions require products to be "attractive" to potential buyers. These items can be everyday things, household appliances or cars.

The surface model is a set of interconnected surfaces. There are two main types of stylistic and technical differences. In the former, greater attention is paid to the visual requirements and the proper continuity of the patches.

Technical areas can be created in countless ways [5, 6]. An example may be the drawing or rotation of a profile, but also a sectional opening or filling of a restricted area. Then the thickness of the material or the filling of the material bounded by the surface is added to the surface.

At the end of the model, reinforcement in the solid modelling technique is performed. The combination of both methods is called hybrid modelling [7]. For formalities, it should be noted that there are also other modelling methods such as the design of sheet metal designs, but they will not be the subject of this study.

Considering different modelling techniques, it is important to mention synchronous and sequential modelling. The main difference between these two methods is the history of the operation. In the sequential modelling technique, a parametric model with history is created. It is easy to change some structural parameters such as rib thickness or radius of rounding. The change is introduced only to enter a different value for the parameter. On the other hand, synchronous modelling only produces a geometric model. Modifications can be made by performing a new operation, such as retraction of the model wall by a specified value.
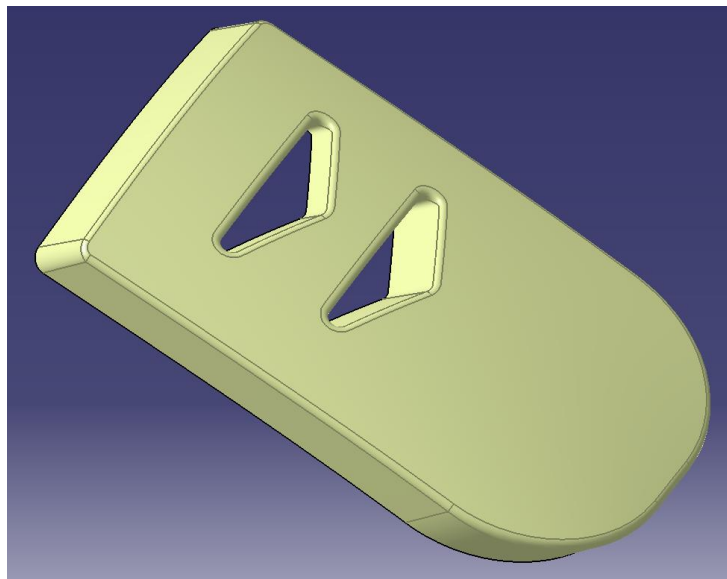
Fig. 2. Example of a surface model (own study)

There is also a surface modelling method based on creating a surface on a set of points. This collection is obtained by scanning the finished item with a 3D scanner. This technique is called reverse engineering [8]. For formalities, it should be noted that there are also other modelling methods such as the design of sheet metal designs, but they will not be the subject of this study.

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3. Mathematical bases of surface modelling

The basic elements that make up the surface model in the computer structure record are curves and surfaces. Both in computer graphics and CAD applications are used to describe equations or systems of parametric equations [9, 10].

In the Figure 3 the surface model of the torus is presented, described by the parametric equations (1) and general (2) [11]. The model was made in Octave with a syntax such as MATLAB [12].
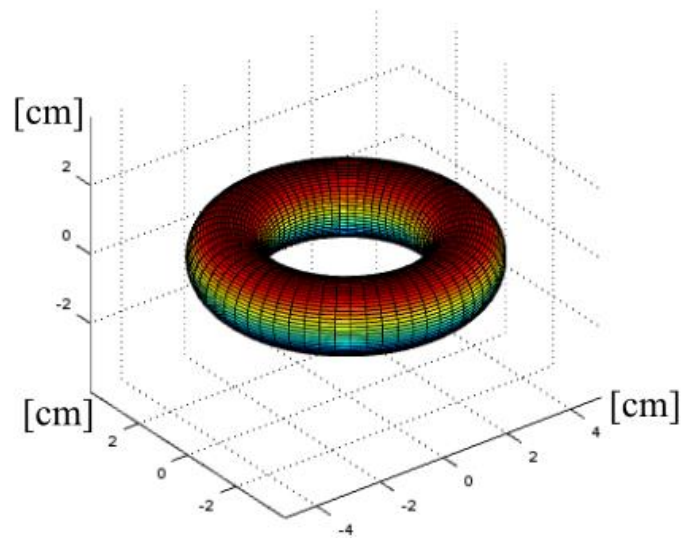
Fig. 3. Torus surface model (own study)

$$\begin{cases} \text{x=(R+rcosu)cosv} \\ \text{y=(R+rcosu)sinv} \\ \text{z=rsinu} \end{cases} \tag{1}$$

$$\left(\sqrt{x^2+y^2}-R\right)^2+z^2=r^2 \tag{2}$$

where:

$$u,v \in [0,2\pi]$$
$$R=3$$
$$r=1$$

CAD environments use parametric curves defined by control points. Such curves are called Bézier curves, described by the system of polynomial equations. Any point on the curve can be described by the formula for the control points pi for i = 0, ..., n [9].

$$p(t) = \sum_{i=0}^{n} p_i\, B_i^n(t) \tag{3}$$

where:

$$B_i^n(t) - Bernstein's\ base\ polynomial$$
$$B_i^n(t) = \binom{n}{i} t^i (1-t)^{n-i}$$
$$t \in [0,1]$$
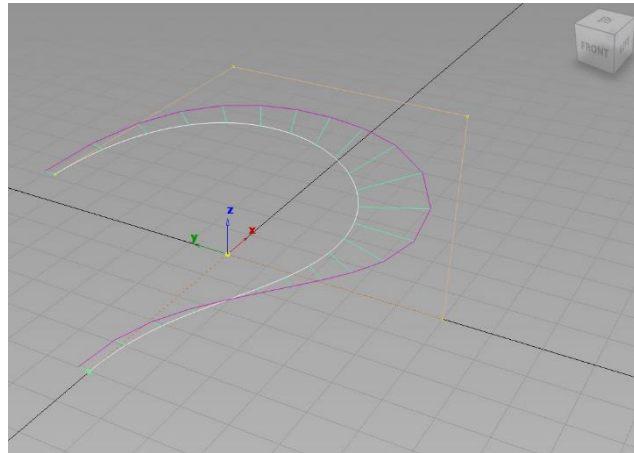$$n - Number\ of\ degrees\ of\ polynomial$$

Fig. 4. Bézier curve example (own study)

The basic surface description is based on the Bézier rectangular surface panels. These are the functions of two variables u and v. They represent a unit square in space. They generalise Bézier's curves. Any point on the surface can be described by the formula (4) [9].

$$p(\text{u,v}) = \sum_{i=0}^{n} \sum_{j=0}^{m} p_{ij} B_i^n(u) B_j^m(v) \qquad (4)$$

where:

$$B_i^n(u), B_j^m(v) - Bernstein's\ base\ polynomial$$
$$\text{u,v} \in [0,1]$$
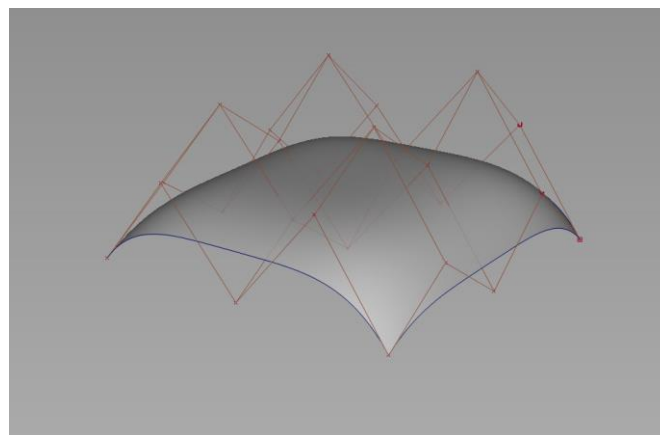$$\text{n,m} - Number\ of\ degrees\ of\ polynomial$$

Fig. 5. Example of Bezier surface panel (own study)

The more advanced methods of describing geometry are curves and NURBS surfaces. NURBS (nonuniform rational B-spline) curves are rational curves, with uneven distribution of nodes (used to define base functions), glued together from several polynomial curves. They are the most common ways of representing curves in CAD programs. They allow much more precise definition of shapes than Bézier's polynomial curves. NURBS surfaces are a generalisation of NURBS curves in a similar way as shown for Bézier curves and surfaces.

4. Stylistic surfaces and surface quality analysis

These sections will show how to design and analyse product quality using stylistic surfaces. An example will be the model of the front of a moped casing. The styling surface is made in Autodesk Alias AutoStudio 2016. This is a specialised environment for creating surface models, analysis and visualisation [13].

The first stage of the design process was the preparation of a symmetrical, rectangular surface panel [14]. A grid of control points was created on the lattice. Control points were connected by lines called Hulls. The prepared surface panel was symmetrical to the plane shown in the Figure 6.
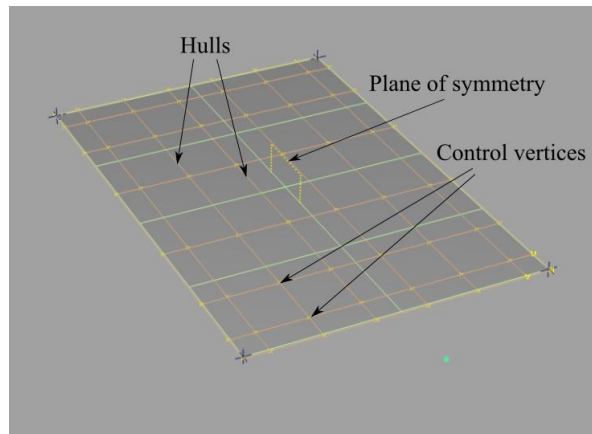

Fig. 6. Rectangular Surface Plate (own study)

The styling surface was defined by precisely moving control points using tools available in the Alias environment [13]. Geometry created in this way is called the free surface. The finished surface together with the visualisation of the distribution of control points is shown in the Figure 7.
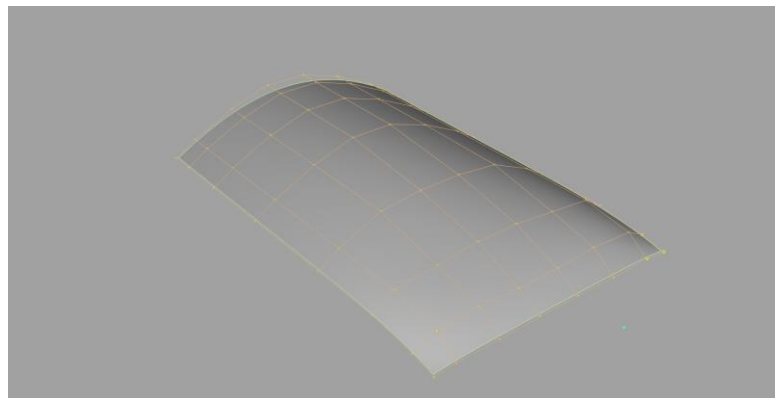

Fig. 7. Stylistic surface A class (own study)

Then the quality of the prepared surface was analysed. The first step in the analysis was to check the distribution of curvature changes. For this purpose, the lines connecting the control points (hulls) were used. Curved curvature contours were applied to the curvature curves by using the Curve Curvature Tool. Curvature was analysed in two directions: u and v.
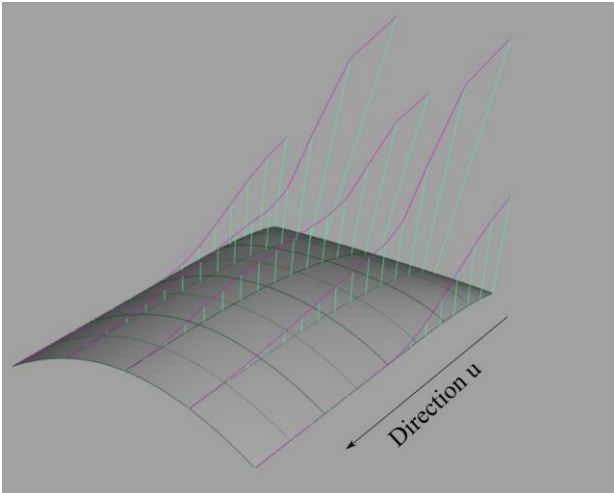
Fig. 8. Curve towards u (own study)

Based on the analysis, it was found that the distribution of curvature in the u direction is satisfactory. The surface was continuous according to the G3 criterion, i.e. the change of curvature did not include sharp passages. This is clearly visible in the Figure 8. The course of curvature contours was smooth, i.e. there were no sharp curves of these curves.
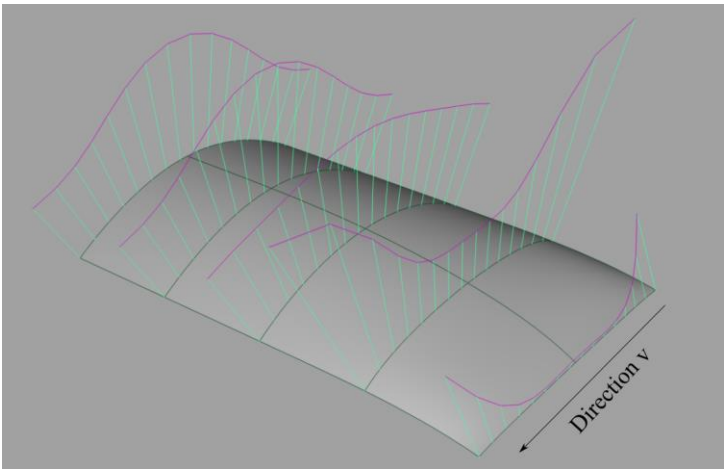

Fig. 9. Curve towards v (own study)

In the Figure 9 the distribution of curvature in the direction v is presented. The continuity of G3 was also preserved here. Surface shape was correct. In addition, the geometry in the direction v was more complicated than in the direction u.
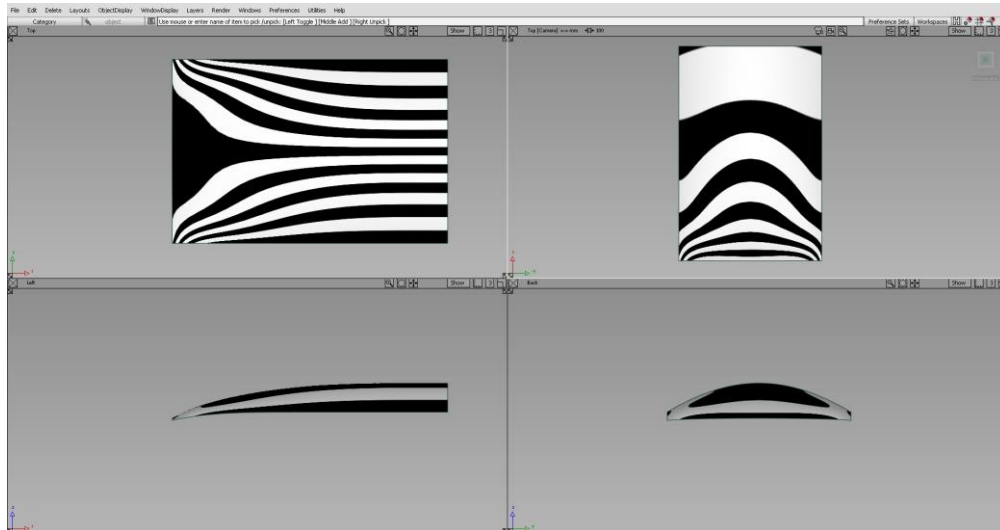
Fig. 10. Distribution of the "zebra" (own study)

Another method of surface quality evaluation was the analysis of the "zebra" constellation line [15]. This is shown in the Figure 10. The transitions on each band were smooth in each of the rolls. This indicated that the surface was continuous at least according to criterion G2. This also allowed to conclude that the distribution of light reflections would be correct. Surface met A-class surface requirements.

5. Product project and technological analysis

Product design begins with the import of the stylistic surface into the CAD environment. The authors used Catia V5. The design assumptions are also important. The housing had to be strong. In addition, the material had to be prone to machining by injection moulding. Acrylonitrile-butadiene-styrene copolymer (ABS), inter alia, meets these conditions. This material is commonly used in the automotive industry for a variety of covers [16].

The technological assumptions related to the selected plastics were [17]:

- housing thickness t,
- rib height - 3 * t + 0.85 mm,
- rib width in base - 2/3 t,
- minimum internal radius - ½ t,
- technological slope - 1° - 3°.

The model had a thickness of 3 mm. Therefore, the width of the rib at the base was set at 2 mm. Such a selection of dimensions would prevent the formation of unsightly material on the product surface. In addition, the inner radius was set at 2 mm and the technological slope of the walls was 2.5°.

The first step in the design of the construction was to prepare a contour of the surface limiting the stylistic surface patch. It was necessary to give it certain dimensions. For this purpose, a sketch of the given dimensions was made. The sketch was projected onto the stylistic surface. Dimensional compatibility was checked. In addition, two profiles of ventilation openings were prepared. Their task was to air flow under the cover and aesthetic considerations. Sketches of holes were also dropped on the surface. Then all the contours were made with the removal operation in the direction of deformation [18]. The results of these operations are shown in the Figure 11.
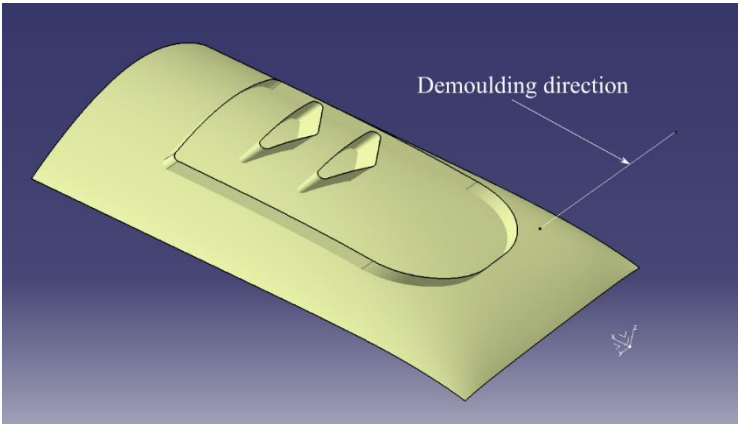
Fig. 11. Technical areas drawn in the direction of deformation (own study)

The external technical surface with the stylistic surface was rounded with continuity G0 – EdgeFillet operation. On the other hand, for stylistic reasons, the internal openings were rounded with G2 continuity -- StylingFillet [5]. This is shown in the Figure 12.
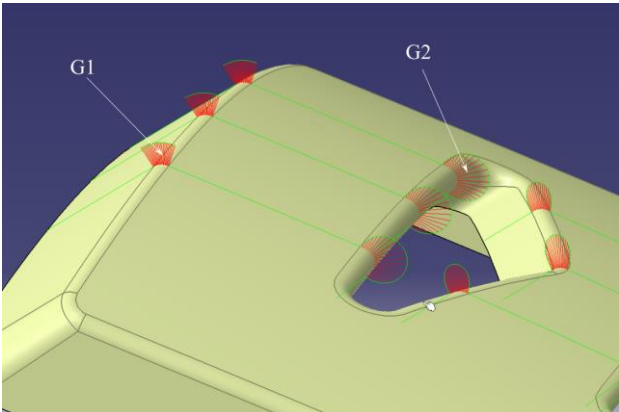

Fig. 12. Different types of rounds (own study)

Material thickness is applied to the surface model. The body formed in that way, at a later stage was cut off by the offset of the stylistic surface supplemented by the geometry of the fasteners. The effect is shown in the Figure 13.
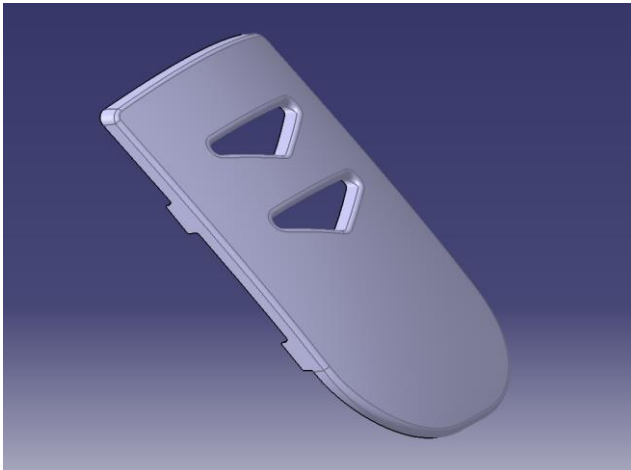

Fig. 13. Solid model (own study)

The last step was to add ribs according to the assumptions. The rib sketch was made [19]. Later, it was pulled out towards the deformation and cut to the desired shape. The technological slopes of the walls were then given and the sharp edges were rounded. The final model is shown in the Figure 14.
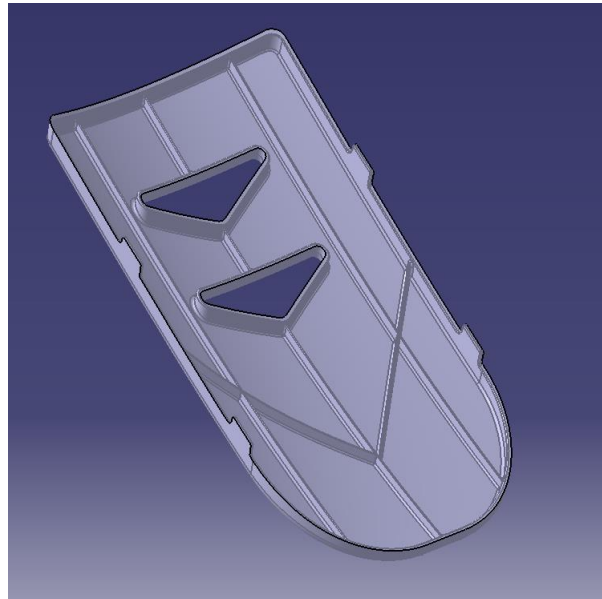

Fig. 14. Model with ribbing (own study)

The prepared model should be checked for deformability. For this purpose, an analysis of technological tides was carried out [20]. Catia V5 used the Draft Analysis tool [5]. The effect is shown in the Figure 15.
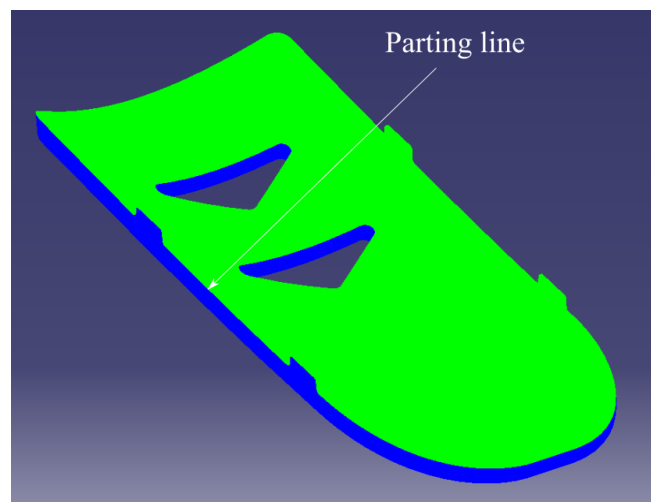

Fig. 15. Analysis of technological tides (own study)

At the border of the two colours contact there is a line of division of the mould. The analysis showed no deviations of less than 2.5°. Thanks to this, the made product can be easily removed from the mould. The product was designed correctly.

6. Summary

This publication describes how to design products using stylistic surfaces. In addition, an analysis of the quality of A-class surface and technological model was made. The result is a technologically feasible model that can be successfully used in industry. Autodesk Alias AutoStudio 2016 software was used to design the styling surface. It is a program that has advanced tools for A surface design and analysis. These tools make it much better for this type of work than regular CAD software. Catia V5 software is used for the execution of technical surfaces and ribs. This environment allows to work on solid models and has the tools necessary to work. This greatly accelerates the design work. Combining the advantages of both environments allows for quick and precise design of products using stylistic surfaces.

7. References

[1] T. Winkler, *Wspomaganie komputerowe CAD/CAM,* WNT, Warszawa, 1997.
[2] J. Bai et al.,"Design reuse oriented partial retrieval of CAD models," *Computer-Aided Design*, vol. 42, pp. 1069–1084, 2010.
[3] W. Przybylski, M. Deja, *Komputerowo wspomagane wytwarzanie maszyn: podstawy i zastosowanie*, WNT, Warszawa, 2007.
[4] T. Dziubek, B. Sobolewski, *Projektowanie przestrzenne CAD 3D*, Fundacja ECCC, Lublin, 2016.
[5] M. Michuad, *CATIA Core Tools: Computer-Aided Three-Dimensional Interactive Application,* McGraw-Hill Education, Columbus, 2012.
[6] Catia V5 HELP, Dassault Systemes.
[7] A. Wełyszko, *CATIA V5 - Sztuka modelowania powierzchniowego*, Helion, Gliwice 2010.
[8] M. Ferdynus, K. Imieliński, Zastosowanie technik inżynierii odwrotnej w modelowaniu powierzchniowym na przykładzie projektu bocznego lusterka samochodowego. *Systemy CAD/MES w zastosowaniach praktycznych*, no. 1, Politechnika Lubelska, Lublin 2013.
[9] P. Kiciak, *Podstawy modelowania krzywych i powierzchni: zastosowania w grafice komputerowej*, WNT, Warszawa, 2005.
[10] P. Kiciak, *Geometric Continuity of Curves and Surfaces*, Morgan & Claypool, Williston, 2016.
[11] I. N. Bronsztejn, *Nowoczesne kompendium matematyki,* PWN, Warszawa, 2007.
[12] R. Pratap, *Matlab7 dla naukowców i inżynierów*, PWN, Warszawa, 2013.
[13] Autodesk Alias 2016 Help, Autodesk.
[14] J. Jiang et al., "A feature-based approach for detecting global symmetries in CAD models with free-form surfaces," *13th International Conference on Computer-Aided Design and Computer Graphics,* 2013.
[15] B. Putz, Metody oceny gładkości powierzchni krzywoliniowych do zastosowań CAD/CAM, Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa, 2002.
[16] D. V. Rosato, D. V. Rosato, *Injection Molding Handbook. Second Edition,* Chapman and Hall, London, 1994.
[17] H. Domininghaus, *Plastics for engineers: materials, properties, applications,* Hanser, Munich, 1993.
[18] P. Pękała, "Modelowanie powierzchniowe w systemie CATIA V5," *Postępy Nauki I Techniki*, vol. 8, pp. 129-136, 2011.
[19] H. Zhu, "Automatic Hierarchical Mid-surface Abstraction of Thin-walled Models based on Rib Decomposition," *14th International Conference on Computer-Aided Design and Computer Graphics*, 2015.
[20] M. Fedrynus, "Analiza jakości powierzchni i technologiczności wyrobu w systemie Catia V5 na przykładzie modelu obudowy lusterka samochodowego," *Postępy Nauki i Techniki,* vol. 7, pp. 44-51, 2011.