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Descriptive Geometry for CAD Users: Ribs Construction

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Abstract. In 3D modeling CAD users often face problems that can be successfully analyzed and solved only by the methods of Descriptive Geometry. One such problem is considered in this paper: the construction of structural elements of machine parts known as stiffening ribs. In addition, a possible geometry of ribs is analyzed and a review is performed of tools for its modeling available in up-to-date CAD packages. Some features are shown that are useful in representing parts with ribs in technical drawing manuals. An innovative approach is developed for educational purposes.

Key Words: stiffening rib, Descriptive Geometry, CAD

MSC 2010: 51N05, 97U50

1. Introduction

Most current curricula suggest that Descriptive Geometry training be done concurrently with practicing the use of one or more CAD packages. As students begin to use the powerful 3D modeling capabilities of these packages for solving problems of classical Descriptive Geometry, they also are mastering CAD. They often solve positional and metrical problems by modeling geometrical objects and their interaction in virtual 3D space [3, 6], thereby avoiding Descriptive Geometry methods. Afterward students do not see the necessity of spatial problems being solved by using plane images and they lose interest in the study of Descriptive Geometry. That impedes their academic progress and their training as engineers. It can be argued that the study of Descriptive Geometry is not possible without clear examples of how its apparatus works in solving problems that arise in the process of 3D modeling. Let us examine one such example.

2. Standard feature for rib construction in CAD applications

Many CAD packages of various levels have in their structure a standard feature [13] that makes it possible to design stiffening ribs in a solid model. In many cases this feature is named *Rib*

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(Autodesk Inventor, KOMPAS-3D[1], Solid Edge, SolidWorks) [1, 8, 11, 12] but may be called by a different name, for instance *Profile Rib* (Creo) [4, 5], *Stiffener* (CATIA) [2], *Dart* (NX) [10] and so on. User interface elements for calling up the operation of rib construction look practically identical in the most packages and may be easy recognized (Figure 1).

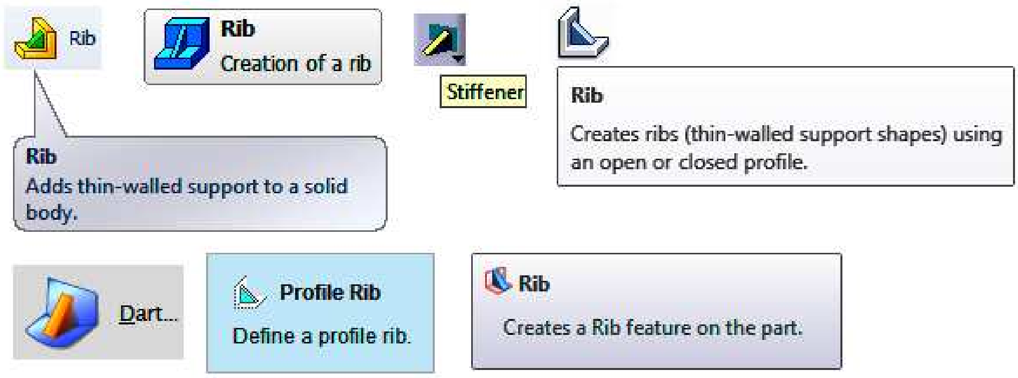

Figure 1: User interface elements for initiating rib construction in several popular CAD packages

Typically, ribs are constructed to strengthen parts in a design to prevent unwanted bending. A standard rib feature in CAD applications is a special type of extruded feature out of open or closed sketched contours. Before constructing a rib in the model, it is necessary to create a sketch defining the shape and position of the rib. The rib is constructed from the sketched line to the body. As a result, a thin wall of a specified thickness is formed that is limited by the sketched line on one side, and by the body's faces on other sides. The specified thickness of the rib is normal to the sketch plane and the material is extruded planar to the sketch (Figure 2).

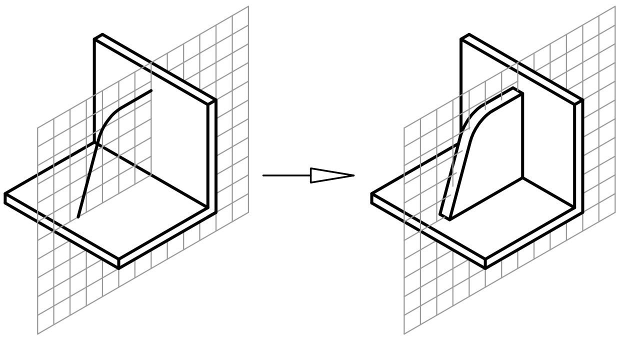

Figure 2: Sketched contour and the result of rib construction

Certainly, ribs in a model also can be constructed without this standard feature from scratch using manual methods. However, application of such a feature makes it possible to simplify and automate the process of rib construction [13] because the procedure combines several operations. These include extension of the rib contour to its intersection with the solid (if necessary), extrusion, union of solids, the ability to add a draft of rib faces and so on.

[1]KOMPAS-3D is a mid-range Russian CAD system widely used in Russia, Ukraine and other ex-USSR countries, including an educational process.

3. Problem definition

The overwhelming majority of students face difficulties in constructing the simplest rib (the contour in the sketch is a segment of a straight line) that borders on the end face of a surface of revolution (by the problem definition) using the standard feature described above. A right circular cylinder or truncated cone is usually used in a design as a surface of revolution. CAD users place one end of the sketch's contour on the end face of the surface of revolution, but that makes rib construction by means of the feature-based tool impossible. The feature definition error message usually contains something like *"Topological operators: invalid profile body"* (CATIA) or the more detailed *"Could not identify valid feature volume(s) to add to the part. Edit feature inputs (profile, direction, side, or extent) or cancel the feature"* (Solid Edge). CAD users find it difficult to understand the error and find a correct solution. People generally presume this error is a program bug because in other cases, such as constructing a rib between plane surfaces or a rib that borders on a surface of revolution but not on its end face, the rib construction operation is executed without any trouble. In this case Descriptive Geometry is the effective tool for analyzing, explaining and solving the problem.

4. Analysis and solution

Let us examine a right circular cylinder as a surface of revolution to which it is necessary to construct an inclined rib. When the rib obtains its thickness perpendicular to the sketch plane, the sketch's contour generates an inclined plane of the rib which intersects with the surface of revolution. As a result of that, we have the classical problem of Descriptive Geometry, namely, the intersection of a cylindrical surface with an inclined plane. As it is known, the section line is an ellipse. In this case, its location is out of the existing geometry on the extension of the cylindrical surface touching the end face of the cylinder at a point A (Figure 3, left), and consequently the operation of rib construction cannot be executed.

For successful execution of the rib construction operation, points B and C must be located on a circle of the upper base of the cylinder or below it. What is the distance l to which it is necessary to displace downward the point A of the end of the sketched line in order that points B and C are found exactly on the circle of the base? This distance $l = DE$ may be determined by elementary mathematical calculations (see Figure 3).

From the triangle OEG we obtain

$$OE = \sqrt{R^2 - \frac{t^2}{4}},$$

where R is the radius of the cylinder, and t is the thickness of the rib. Then

$$AE = R - \sqrt{R^2 - \frac{t^2}{4}},$$

and from the triangle AED follows

$$DE = \frac{AE}{\tan\alpha} = \frac{R - \sqrt{R^2 - \frac{t^2}{4}}}{\tan\alpha},$$

where α denotes the angle between the inclined plane of the rib and the axis of the cylinder. In this case $l = DE$, if the displacement of the sketched line is parallel to itself, that is $\alpha = const.$

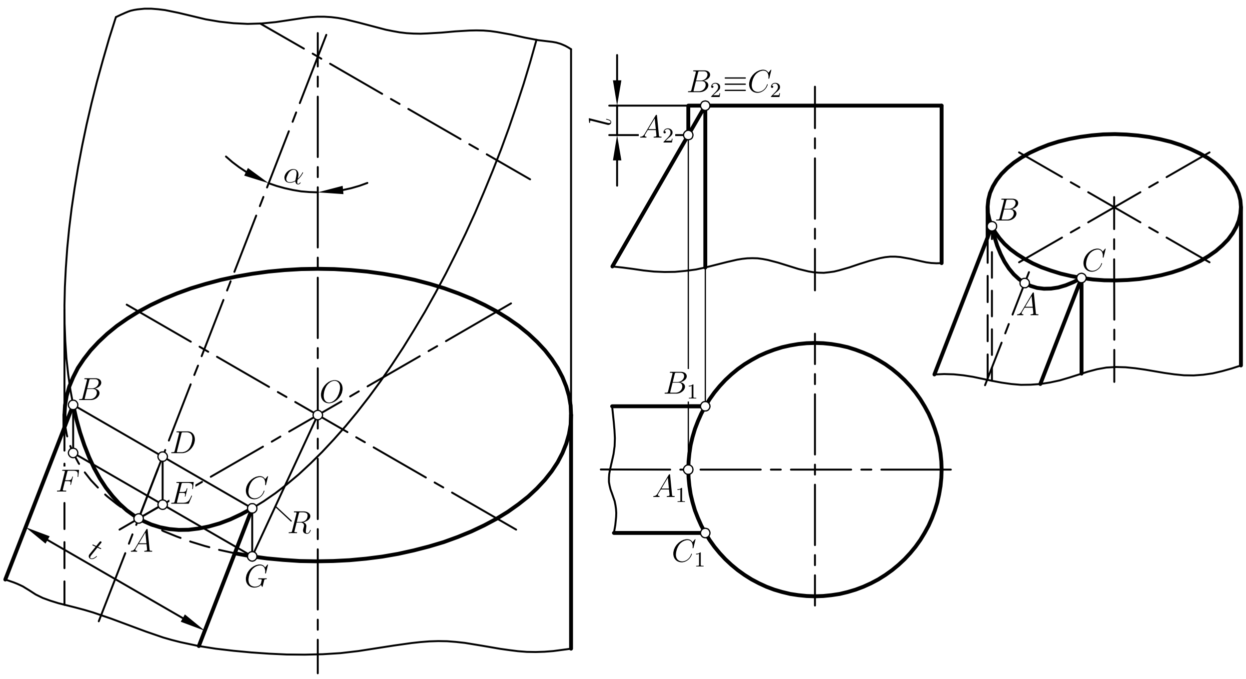

Figure 3: Intersection of the cylinder with the inclined plane (left) and an example of successful rib construction (right)

There may be a question: What is the practical accuracy of assignment of the distance l so that points B and C will be located exactly on the circle but not in close proximity to it? This question of modeling accuracy is especially critical if the model is intended for analysis in CAE applications. It will be necessary to additionally modify a solid or finite element model. Otherwise closely spaced nodes of mesh may lead to degenerative finite elements, that is, to poor quality of the finite element mesh.

Another question in connection with the previous one is this: Is it possible to find the exact distance l by means of graphic constructions without approximate mathematical calculation? The answer is "yes" and it can be done reasonably easily. For that, it is necessary additionally to construct the top view of the cylinder with the rib in the sketch plane (Figure 4).

In Figure 4, we have K_2A_2 as the initial line in the sketch for rib construction; $K_2'A_2'$ is a new position of this line in the sketch when points B and C will be located exactly on the circle of the upper base of the cylinder. $A_2A_2' = l$ is the distance of the displacement of the point A in the vertical sketch plane.

Let us explain the constructions. The given cylinder is projected on the sketch plane by means of CAD tools. The circle of radius R, which is the same as the radius of the cylinder, is constructed orthographic to the contour line of the cylinder. Two symmetrical, straight horizontal lines are constructed parallel to the axis of the circle at a distance of $t/2$. Although one line is enough for the problem solution, having two of them provides further clarity. Thus, we find horizontal projections B_1 and C_1 of points at which edges of the rib with a thickness t intersect the cylindrical surface (see also Figure 3). Because points B and C lie in the inclined plane of the rib, its vertical projections B_2 and C_2 will be located on an extension of the line segment K_2A_2.

Obviously, it is possible that two versions of a rib should be constructed. In the first case, the angle between the inclined plane of the rib and the axis of the cylinder is $\alpha = \mathit{const.}$ In that case, the distance from point C_2 to the upper base of the cylinder is the displacement

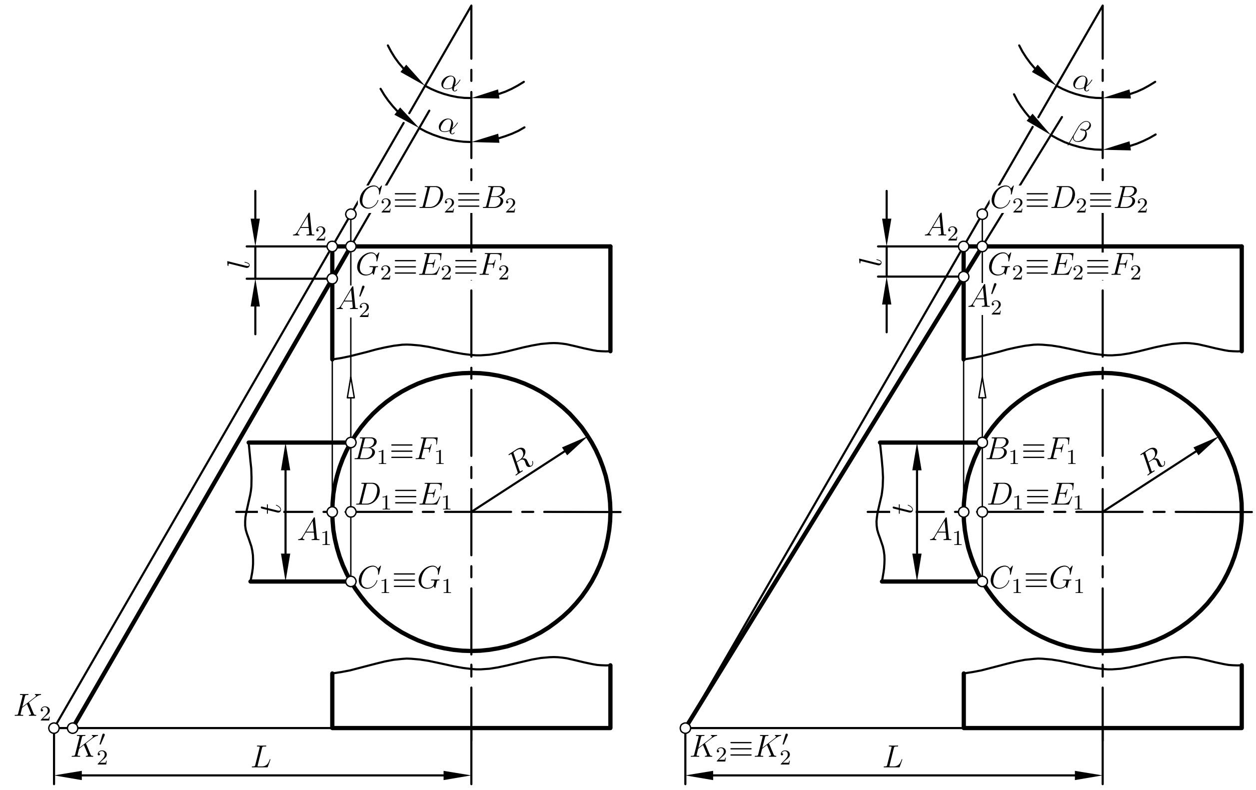

Figure 4: Graphic positioning of the line in the sketch for the rib construction.
Left: $\alpha = const.$, right: $L = const.$

being sought:

$$C_2G_2 = l = A_2A_2'.$$

A required location of the sketch's contour is a line segment $K_2'A_2'$ on a straight line which is passed through the point G_2 parallel to the line segment A_2K_2 (Figure 4).
In the second case, the distance from a lower point of the rib's fixation to the axis of the cylinder is $L = const.$ In this case, it is necessary to construct the straight line through points K_2 and G_2. Point A_2' will be obtained as a result of the intersection of this line with the contour generatrix of the cylinder. The required location of the sketch's contour is then a line segment $K_2'A_2'$, where $K_2' \equiv K_2$. The distance of the displacement $l = A_2A_2'$ is determined from the construction (Figure 4). In CAD applications, every shape-generating operation of modeling on the basis of the sketch may be applied only to the contour that is specified in the sketch plane by the solid line. Consequently, all other lines except the line segment $K_2'A_2'$ must be specified as "construction geometry" using the notation of each CAD program.

However, the rib also may be constructed by means of the standard feature in the case when $\alpha = const.$ and $L = const.$, that is, when the sketch's contour for operation is the initial line segment K_2A_2. For this, before applying the rib feature, it is necessary to extend the cylinder by means of CAD tools so that the inclined plane of the rib can meet with the extended cylinder surface. After rib construction, the extended part of the cylinder and the part of the rib must be cut off by the plane that coincides with the base of the given cylinder (Figure 5).

Is a version of rib construction possible when all three points A, B and C (Figure 3) are located on the circle of the base of the cylinder? It is possible, but the rib in this case is not

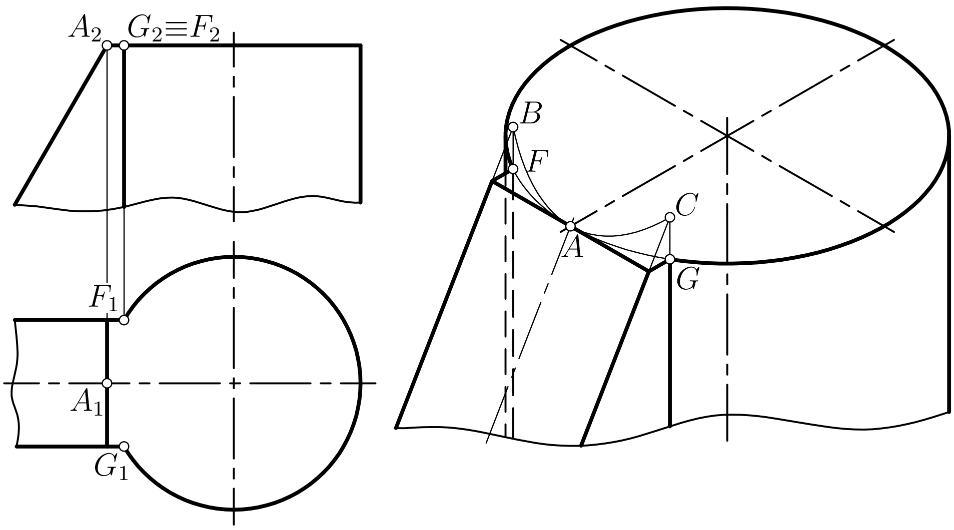

Figure 5: A version of rib construction when its extended part is cut off

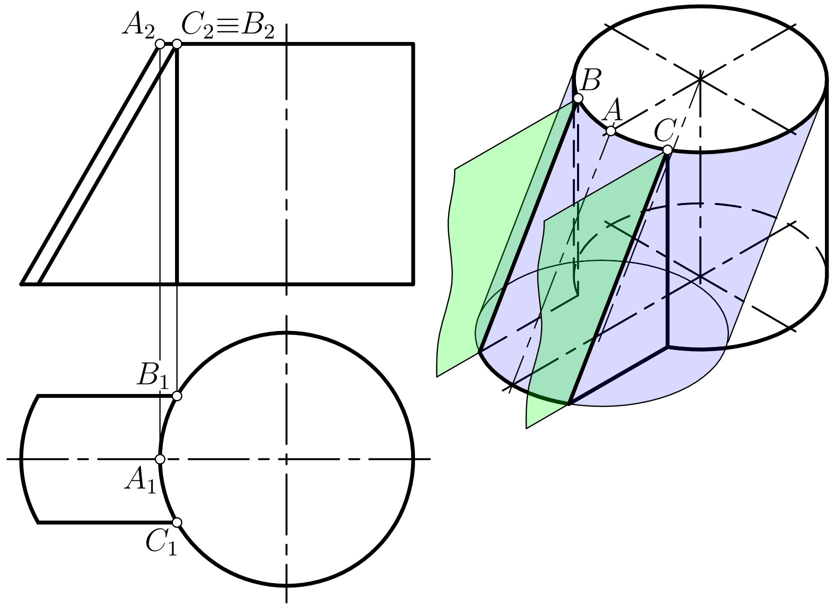

Figure 6: A rib with an oblique cylindrical surface

straight. The inclined surface of the rib is a surface of an oblique circular cylinder (Figure 6) or a cone.

Most popular CAD applications do not include a special feature or operation for constructing such “cylindrical ribs”. Therefore, when this is necessary, one can use the surface modeling or solid modeling tools found in each program.

In the CAD package Creo Parametric, from PTC (created on the basis of Pro/ENGINEER), the *Profile Rib* feature allows construction of “conical ribs” in addition to the usual straight ribs. The rib type is automatically set according to the attachment geometry: a straight rib attaches to planar surfaces, a rotational rib attaches to surfaces of revolution [4, 5]. A sketch’s contour revolves about the axis of the parent making a wedge with a conical angled surface. The wedge is then trimmed with two planes which are parallel to the sketch plane. The distance between the planes corresponds to the thickness of the rib (Figure 7).

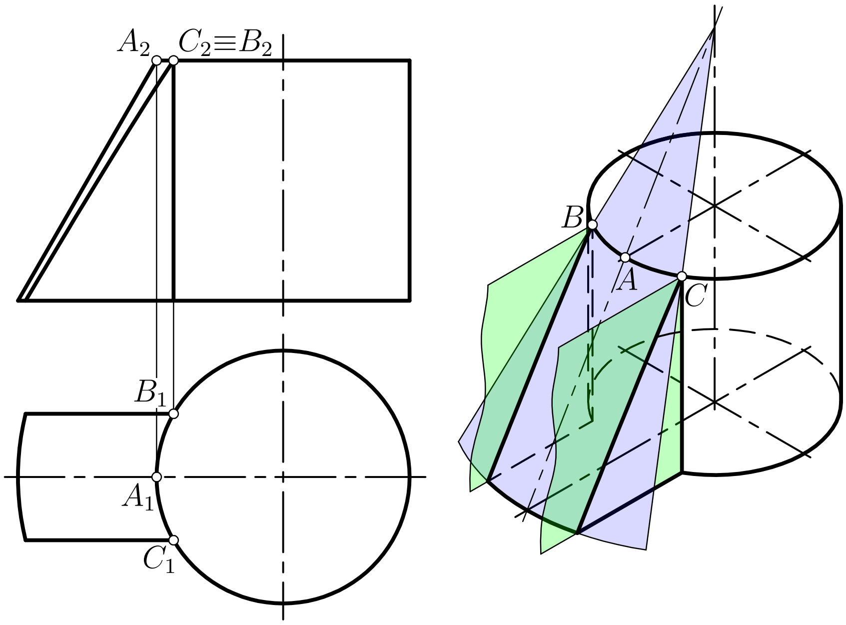

Figure 7: A rib with an oblique conical surface

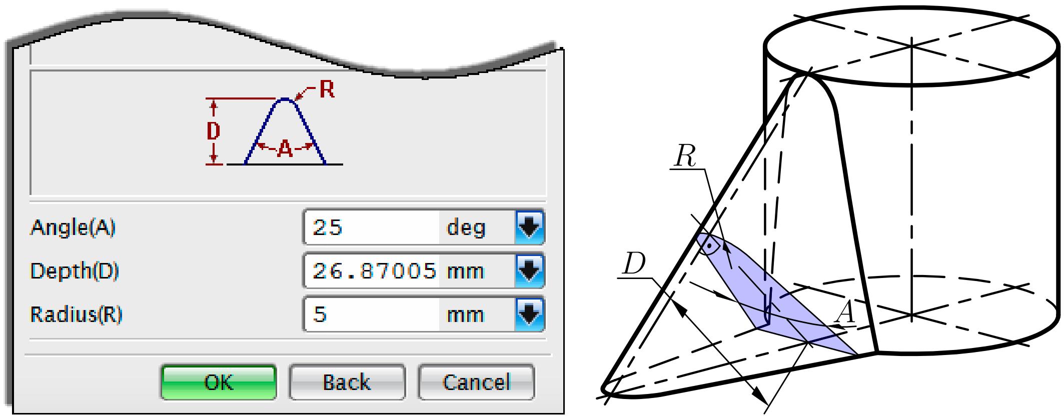

Figure 8: A rib constructed in NX using its standard feature *Dart*

The edges of the rib are parts of conic sections, namely hyperbolas.

In the end, it must be noted that in the CAD package NX (formerly known as Unigraphics) a standard feature named *Dart* allows construction of ribs with a draft of rib faces and an oblique cylindrical surface [10]. A radius of the cylindrical surface R and an angle A (see Figure 8) cannot be equal to zero, that is, the standard straight rib or “cylindrical rib” with vertical lateral faces cannot be constructed using this feature.

Smooth transitions, generally called *fillets*, often are constructed along intersection lines of rib faces and a surface of revolutions. The simplest version of an edge fillet, present in practically all CAD applications, is a transition by means of the cylindrical surface of a constant radius when this surface is tangent to both adjacent surfaces (so-called tangent continuity or $G1$ continuity). For a straight rib with points B and C located on the circle of the cylinder’s base (see Figure 3), all of the above-mentioned CAD applications produce the result shown in the left image of Figure 9.[2] Some part of the rib with fillets is located

[2] Per latest releases of the CAD software at the time of paper publication.

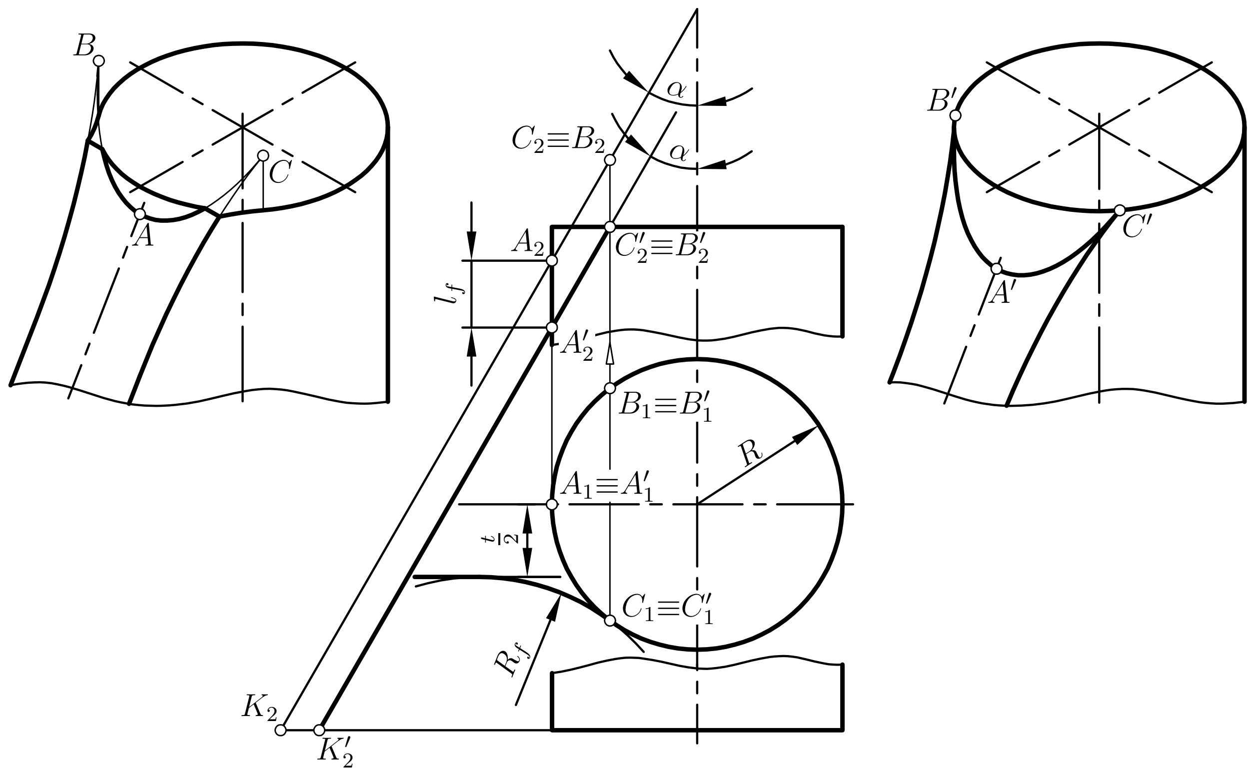

Figure 9: Edge fillets for a straight rib

beyond the existing geometry and is automatically cut off during operation execution. It is necessary to displace the sketch's contour by the distance l_f if the full (not cutoff) version of the fillet is required. This distance also can be easily found graphically by means of additional constructions in the sketch plane (see Figure 9). For better visual clarity, the thickness of ribs and fillet radii in all figures of this paper intentionally are greater than it is usually assumed for thin-walled elements.

In Figure 9, K_2A_2 is the initial sketched line for rib construction, and $K'_2A'_2$ is a new position, when the full version of the fillet for a given radius can be obtained. R_f denotes the fillet radius.

A version of the solution when $\alpha = const.$ is shown in Figure 9, with the result of filleting for the corrected rib on the right. A version for $L = const.$ would be solved in a way similar to what is shown in Figure 3.

5. Representation of ribs in students' drawings

It is worth noting some frequent mistakes in the representation of ribs in students' drawings. During freehand sketching or making 2D drawings of designs with ribs, many students incorrectly represent them in orthographic views (see Figure 10). It is obvious that front and top views (the first angle projection) do not correspond to each other for any rib geometry described above (see Figures 3, 5–7). In this case application of 3D modeling and generation of 2D views from the model allow visual detection and analysis of mistakes in drawings.

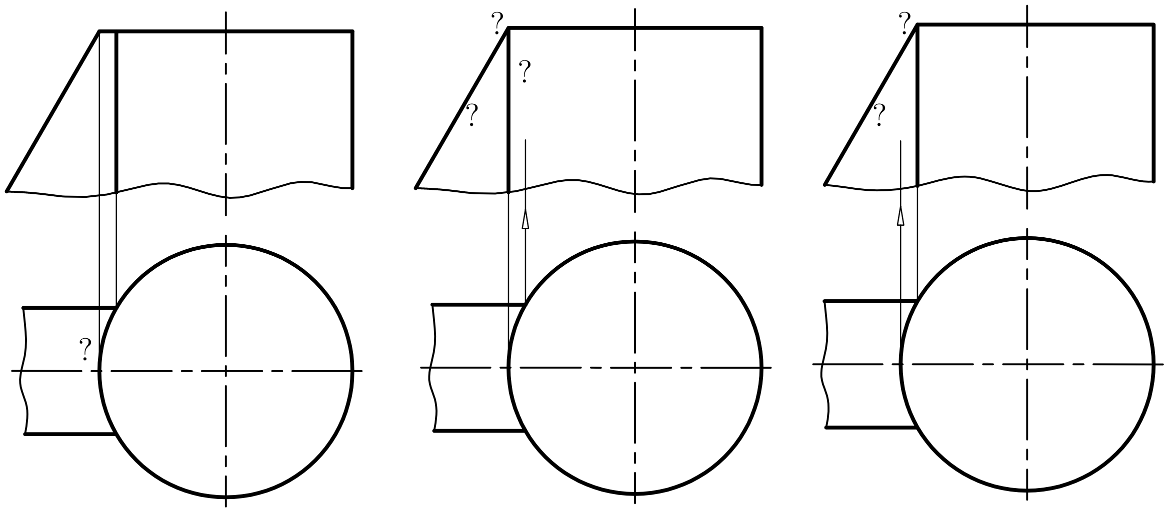

Figure 10: Versions of incorrect representation of ribs in students' drawings

6. Representation of ribs in textbooks

Drawings or pictorial images of designs with ribs often are found in modern educational literature on technical drawing as examples or exercises for modeling. Incorrect drawings can be found, e.g., in [7, Excercise 6.22, p. 200] or in [9, Problem 12.25, p. 466]. A height of rib or a distance from the upper point of a rib's fixation to the upper base of a surface of revolution (the minimal distance may be a fraction of a millimeter and therefore imperceptible on an image at this scale) often is not given in these drawings. A student with no prior experience with this problem will have some trouble in creating a 3D model according to this image. On the one hand, such exercises visually set up a task that motivates students to find solutions. Generally, however, this may be successfully performed only under the instructor's guidance. In the process of unassisted modeling, students' questions usually remain unanswered. Strictly speaking, such drawings and pictorial images with ribs are incorrect because they do not contain full information about the geometry of the part. It should be admitted that ribs in most cases do not have very strict requirements for accuracy of manufacturing or location. The angle of rib inclination or its point of fixation often may be freely changed within certain limits without significantly changing the strength properties of the part. However, these limits must be specified in some way if the drawing does not have proper dimensions.

7. Conclusions

As it is, a number of example problems for 3D modeling should be compiled that demonstrate the necessity of analytical and/or Descriptive Geometry for their successful solution. In some cases the graphic method of problem solving on the plane is more reasonable than analytical or 3D methods of modeling with CAD. Demonstrating this requires simple and clear examples. Such examples will help students to understand that Descriptive Geometry continues to be a vitally necessary part of their education.

Sometimes it makes sense to include elements in problems that have specific geometry but allow construction of several versions of design. For example, in the case of rib construction, the thickness of the rib and its location may be known but the type of rib is not precisely specified. Such problems allow students to study and analyze geometry and design products on the basis of simple geometric shapes. A successful lecturer has to foresee possible difficulties an entry-level engineer encounters during geometric modeling. Therefore, he must solve actual engineering tasks regularly in order to discover the range of possible difficulties in the problems.

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