GEOMETRICAL DATA EXTRACTION OF AXISYMMETRIC PARTS FROM THE B-REP MODELS

Grzegorz Nikiel

Summary
For manufacturing processes planning the different product data are required. Especially, a geometrical description of the manufactured element is indispensable. Widely applied for this aim the 3D models have many advantages in comparison to the 2D models and usually they are more useful. Sometimes it is different. Such situation is in case of the axisymmetric parts, machined on the lathes. A manufacturing process planning can be carried out on basis of a 2D model and often so this is made. Therefore, in this paper an automatic procedure for conversion of the rotational parts 3D model to the 2D model is introduced. In this approach the B-Rep model representation method is applied and a STEP file (ISO 10303:203) as the data carrier is used. Moreover, an example is presented where effectiveness of the described procedure was confirmed.

Keywords: CAD/CAM, 3D models, manufacturing processes planning, STEP standard

1. Introduction
For manufacturing processes planning, especially for CNC programs design, many product data are necessary. The geometrical form of manufactured part is one from most important information. In modern approach where the computer aided systems are used (CAD/CAM systems) usually this information...
has electronic form where the CAD applications are the source. On stage of
the part design more and more seldom the 2D models are used. Therefore 3D
models should be treated as a potential source of the geometrical form on next
stages of manufacturing process planning. They can contain many essential
information (directly in a CAD environment) but data exchange between CAX
programs is joined inevitably with the partial loss of them [1]. Moreover, not
always 3D models are indispensable, more useful can be them 2D equivalents.
Best example of such situation are the axisymmetric parts, machined on the
turning centres [2-5].

In practice a semi-automatic creation of the 2D documentation on basis of
3D models is possible and use of them to manufacturing processes planning. But
such approach possesses one essential defect – necessity of a suitable model
extraction through the superfluous informations elimination, e.g. the additional
views, annotations, dimensions, etc. Considerably easier in this case can be
different solution – a manufactured part contour extraction from its 3D model.

This aim can be reached into automated way directly in a CAD
environment by use of the accessible program interfaces (e.g. the ActiveX
controls) or indirectly with use of the external application which use a 3D model
exported from commercial CAD programs in any neutral format (DXF, IGES,
ACIS, etc.). In view of generality (data import from different CAD programs)
more profitable, in opinion of author, is second approach. Therefore this
approach is used and described in the paper.

It is connected with two very important questions: choice of method of
a model representation (model description) and structure of model data for this
representation (carrier of a model data). In the paper [1] is showed that in present
CAD environments dualism of the 3D models representation exists: internal
structure uses the CSG approach (Constructive Solid Geometry), and external,
accessible for other applications, the B-Rep approach (Boundary
Representation). From many reasons the B-Rep approach is less useful for the
manufacturing processes planning. First of all from reason of lack of the
cohesion and additional information about modelled part (e.g. the dimension
tolerances, geometrical tolerances, roughness parameters etc.). Nevertheless, for
import of the basic form of part model this approach is sufficient.

Second question, what one should to decide, is choice of physical way of
the model data exchange between CAX applications. Some alternative solutions
are accessible – e.g. IGES or ACIS. Use of the structure of data given in ISO
10303 standard (called STEP standard) is, in opinion of author, the best solution
[6-9]. The B-Rep model is defined in the area of STEP standard called
Integrated Generic Resources, concretely in part ISO10303:42 [10]. From this is
referred to another area, i.e. mainly for the Application Protocols (AP),
CAD programs are equipped with function of the B-Rep data export in
accordance with mentioned protocols. Often exported STEP files are in the
textual format in accordance with ISO 10303:21 [13]. Infrequently more universal XML files format given in ISO 10303:28 is used [14]. This last became used for export of the 2D contour, where the data structure is given in the ISO 10303:201 [15].

2. Problem formulation

In the analyzed case a task is expressed as follows: to extract 2D contour from 3D model of an axisymmetric part (in B-Rep form) (Fig. 1).

![Fig. 1. An axisymmetric part and its models](image)

The B-Rep representation is a set of elementary faces. If all faces from this set distinguish the closed space then it is treated as an interior of solid model. Then it was possible to calculate its volume, mass and other mass parameters. The B-Rep models is defined in bibliography as a hierarchic structure where on highest level is the modelled object. On the second-rate levels are suitably the faces, edges and vertex points [16-18]. The B-Rep approach is unambiguously defined if the model consists of flat faces. In opposite case description of the model is more complicated (e.g. for cylindrical, conical or toroidal surface). Therefore, in practice for each face two area of data are given [19] (Fig. 2):

- definition of the elementary surface without any limits (e.g. infinitely long cylindrical surface),
- definition of the edges which “cuts out” from an elementary surface the limited face.

For clear definition of the face at least one close loop of the edges is required. If more such loops exist then only one from them is treated as external (Face Outer Bound), however remaining as internal loops (Face Bound) (Fig. 3). The task formulated above can be dissolved if an algorithm become defined for
the elementary surfaces and their limitations analysis. Such algorithm is introduced in next chapter.

Fig. 2. An unlimited elementary surface (a) and limited face (b)

Fig. 3. Difference between edges loop of type Face Bound and Face Outer Bound [19]

3. A 2D contour extraction algorithm for the axisymmetric parts

3.1. Data import

In the first stage of presented algorithm the input data is imported and initially analyzed. In this approach the B-Rep model exported from any CAD programs (e.g. SolidWorks) is used. Moreover, the model has structure in accordance with ISO 10303:203 Application Protocol (AP203) [11, 13]. Many of the commercial CAD programs permits to export the B-Rep models as well in accordance with ISO 10303:214 Application Protocol (AP214) [12] but in area
of model representation it is identical to the AP203. Therefore such models are accepted also.

In the Figure 4 fragment of hierarchic structure of the B-Rep model given in AP203 is showed. On highest level is the Manifold_Solid_BRep class (entition). For a simple model the STEP file contains only one entition of this class. The Manifold_Solid_BRep entition is a set of faces (Advanced_Face class). In the face definition is included two basic relations:

- to the Surface class in which an unlimited elementary surface is given (Face_Geometry attribute),
- to the set of Face_Bound or Face_Outer_Bound entitions (Bounds attributes) in which the edges are defined.

![Diagram](image)

*Fig. 4. General structure of B-Rep model [11]*

In the Figure 5 the Surface subclass detailed structure is showed. In the Elementary_Surface class five basic Surfaces are applied – plane, cylindrical surface, conical surface, spherical surface and toroidal surface. Each of them is defined by characteristic for them parameters (e.g. radius, angle) but always at least one is given – Axis2_Placement_3D class. Through use of this attribute a space orientation for the elementary surface is defined.

More complex are the Face_Bound and Face_Outer_Bound subclasses (Fig. 7) which describe the edges. In generality they are set of elementary edges (a Loop class) and them Edge subclass is defined as a part of the infinity elementary curve (a Curve class, e.g. Line, Circle) through giving two vertex point (Edge_Start and Edge_End attributes). Mentioned definition is supplemented by the additional characteristic parameters (e.g. circle radius) and by the position attributes.
3.2. Transformation of the faces to a Local Coordinate System

A machined part model, created in the CAD programs, can be freely oriented in 3D space. For clearness of further considerations an important assumption was accepted – every analysed model must be transformed to a Local Coordinate System (LCS) into such way that its symmetry axis is identical with X axis of the LCS (Fig. 6). In first step a spatial orientation

Fig. 5. The structure of Face_Geometry attribute [11]

Fig. 6. The World Coordinate System (WCS) and Local Coordinate System (LCS)
of symmetry axis in the *World Coordinate System* is formulated by the means of selected *surface* with one symmetry axis (i.e. cylindrical surface, conical surface or toroidal surface). This selected *surface* in the further considerations is called the *Base Element*. Moreover, the *Base Element* is treated as a basis for the LCS origin point definition. In the coordinates transformation homogenous coordinates approach are applied.

![Diagram](image)

**Fig. 7.** The structure of Face_Bound and Face_Outer_Bound class [3]

### 3.3. An axial section of the single surfaces

In the next step an axial section for single *surfaces* is analysed. This section is executed by the positive XY semi-plane of LCS (Fig. 1). On basis of *edges* set for each *surface* a set of single profiles is created as a result of the axial section. Because set of elementary *surface* was accepted earlier (chapter 0) hence this profiles can be a line section or an arc. In the described procedure a set of the geometrical attributes is calculated (Fig. 8).
For example, in the case of conical surface a line on XY positive semi-plane of Local Coordinate System is a result of the axial section (Fig. 9). For this type of surface only the Face_Outer_Bound limitations are accessible: arcs or lines, nevertheless only the arcs are considered. In consequence a L line is expressed where it consists of a set of points. Moreover, two cases are possible: with two arcs or with one arc.

In first case (two arcs) on basis theorem of Tales the L line is obtained as follows:

\[
L = \{(X,Y) : \begin{cases}
X_{C1L} \leq X \leq X_{C2L} \\
Y = R_1 + \frac{(X - X_{C1L})(R_2 - R_1)}{(X_{C2L} - X_{C1L})}
\end{cases}
\]  \hspace{1cm} (1)

where: \(X_{C1L}, X_{C2L}\) – the X coordinates of arc centres; \(R_1, R_2\) – the radius of the arcs.
In second case (only one arc) the coordinates of C2 point (an arc centre about radius equal zero) must be calculated as follows (Fig. 10):

\[
\begin{align*}
X_{C2L} &= X_{PL} + \frac{R \cdot (X_{PL} - X_{C1L})}{R_i - R} \\
Y_{C2L} &= 0
\end{align*}
\]  

(2)

and the L line is formulated by equation (1).

![Figure 10: Analysis of the edges for limitations of conical surface (with one arc)](image)

### 3.4. Synthesis of 2D contour

The numerous single elements of analysed 2D contour which are obtained as the result of axial section (chapter 0) in the next step must be ordered and transformed to the form of closed contour. Further more, on this stage the repeated segments of the contour are eliminated. Their existence is consequence of the rule of modelling for some surface – a face of the symmetrical surface (e.g. cylindrical surface) is assembled from two identical part.

General idea of the introduced procedure of synthesis is presented in Fig. 11. It is based on sequential search of such element from set of contour elements (chapter 0) for which the coordinates of start point (P1) or end point (P2) are identical with the coordinates of start point (PS) or end point (PE) of the current synthesised contour. Moreover, at the end of procedure it is checked, if the contour is closed. If not then it is automatically closed – a line segment is added which joins first and last points of open contour.
In addition, a mirror function along Y axis is possible to be used for the created contour. This function is motivated by such situation where modelling of suitable orientation of the part in relation to a lathe is necessary (in the tailstock-spindle system). Moreover, it was possible to notice that some commercial CAD programs independently rotate model in the STEP file (e.g. such effect gives SolidWorks). Therefore, this function in the introduced algorithm is necessary.

It is carried out in accordance to the following dependences (Fig. 12):

• for the line segment

\[
\begin{align*}
X_{p1m} &= -X_{p1} \\
X_{p2m} &= -X_{p2}
\end{align*}
\]

(3)

• for the arc segment

\[
\begin{align*}
X_{p1m} &= -X_{p1} \\
X_{p2m} &= -X_{p2} \\
X_{cm} &= -X_c \\
K_{1m} &= 180° - K_1 \\
K_{2m} &= 180° - K_2 \\
dir_m &= 5 - dir
\end{align*}
\]

(4)
where the ‘\(m\)’ index marks the transformed element and its other parameters (e.g. \(Y\) coordinates, \(R\) radius) are identical with the parameters of original element. An \(\text{Dir}\) parameter has two permissible values: 2 (the \(\text{Clockwise}\) direction) and 3 (the \(\text{Counter clockwise}\) direction).

![Diagram](image)

Fig. 12. The geometrical parameters of an element of contour after mirror along \(Y\) axis

3.5. Data export of the extracted contour

In the last stage of introduced procedure the extracted contour can be saved in some file. It is possible to be carried out in three ways:

- in a standard text file in DXF format (if needed by different applications, e.g. for CNC programs simulation),
- in a text file with data structure given in AP201 [13, 15],
- in a XML file with data structure given in AP201 [14, 15].

Data structure given in AP201 [15] for the 2D models representation is a subset of the data structure defined in AP203 [11] which is used mainly for the 3D models representation.

4. An example

Last of all the introduced algorithm became verified by an example. In the SolidWorks 2009 environment 3D model of some axisymmetric part was designed (Fig. 13). Then this model was exported to the STEP text file in
accordance with the AP203. In aim to check correctness of the produced file it was imported to the EdgeCAM 2009. Any errors of data import were not noticed and imported model was visually agreeable with the initial form.

Fig. 13. The modelled part and its dimensions

Fig. 14. Preview of contour of analysed model
Next by use of the application program designed during investigations the described above model became processed. What gave result in form of 2D contour (Fig. 14). Output data in form of STEP file in accordance with the AP201 was saved in the XML form. Its edition in XML Viewer editor confirmed correctness of structure output file. Correctness of data could not become verified from attention onto lack of commercial application accepting AP201 format. Nevertheless, on basis of data in DXF format full confirmation of agreement of both form of model was got. What permits to prove thesis that described algorithm is correct.

5. Concluding remarks

In the paper an algorithm for extraction of 2D contour of the axisymmetric parts from a 3D model given by the B-Rep structure is introduced. A source of B-Rep model was STEP file in accordance with AP203 standard. Formulated algorithm was checked with positive result, also on many other examples here no showed. It will be used in a preliminary stage of complex algorithms for computer aided planning of manufacturing processes, characterized by high degree of automation. Designed during investigations an application program was limited to the elementary surfaces and edges, nevertheless in generality it can become applied also in case of more complicated surfaces and edges, e.g. in form of NURBS models (the Free Form Surfaces). An extracted 2D contour describes only nominal form of the modelled parts, it is devoid of other important informations, e.g. tolerances of dimensions. This defect is resulting from structure of B-Rep model and not from described here processing of it. Therefore, to reach the aim that mentioned data will be sent into simple way between CAx applications the use of other types of models is necessary, first of all based on Features idea.

References


Received in September 2010