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Parametric design of a part with free-form surfaces

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Abstract: 3D solid models for parts with regular-form surfaces (PRFSs) are effectively generated using traditional parametric design techniques. A new model is obtained by changing some parameters defining the model. The parts with free-form surfaces (PFFSs), however, cannot be defined by several parameters. Usually they are defined by some geometric elements like profile curves. The traditional parametric design approaches have not easily dealt with the PFFSs. A method for generating a solid model and an engineering drawing for PFFSs is proposed in this paper: First, the new profiles are generated from input point data. Second, the profile information is extracted from the existing model. Last, the old profiles are replaced with the new profiles. This method can preserve the associative information of the existing model and automatically generate the drawing including views, dimensions, and annotations. The proposed method has been implemented using a commercial CAD/CAM system, Unigraphics, and API functions written in C-language, and were applied to the blades of a turbine generator. Some illustrative examples are provided in order to show the effectiveness of the proposed method.

Key words: Parametric modelling, Free-form surface, Solid model, Drawing
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INTRODUCTION

A 3D solid model is used in various processes such as design, engineering evaluation, drafting, manufacturing, and so on. It is a time-consuming and skill-required job to create a complicated 3D solid model. Most commercial CAD tools support functions to generate engineering drawings from solid models automatically. However, adjusting layouts, dimensioning, and inserting annotations are required and they are tedious and time-consuming work.

Most current CAD/CAM/CAE software utilize a parametric design feature, a method of linking dimensions and variables to geometry in such a way that when the values change, the part and the drawing change as well (Ke *et al*., 2006). A parameter is a variable to which other variables are related, and these other variables can be obtained by means of parametric equations. In this manner, design modifications and creation of a family of parts can be performed in remarkably quick time compared with the redrawing required by traditional CAD.

A part family is a set of parts that have fixed structure and shape with different dimensions. For parts with regular-form surfaces (PRFSs) or common surfaces in a family, the shapes can be defined by the template model, which is the prototype of the model, and a set of dimensions. The PRFSs can be easily modeled by parametric design techniques. A bolt is one of the typical examples for PRFSs. Fig.1 shows the template of a bolt and a table of dimensions to determine a series of bolts. By assigning values to a set of dimensions, a 3D solid model can be simply created and an associated engineering drawing can be generated in a predefined and automated manner (Chang *et al*., 2005; Park, 1997; Kim and Byun, 1998; Chen *et al*.,

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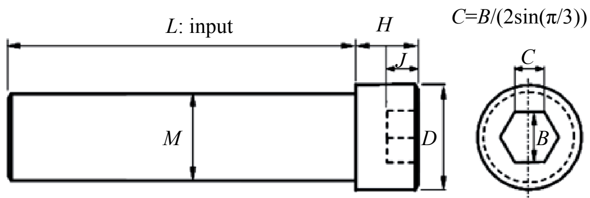
2002).

As for parts with free-form surfaces (PFFSs) like turbine blades, however, the shapes cannot be defined only by a set of dimensions, but must also be defined by a set of geometric elements like profile curves. The traditional parametric design approaches have not easily dealt with the PFFSs.



Name	M	D	H	J	B
$M3$	3	5.5	3	1.5	2.5
$M4$	4	7	4	2	3
$M5$	5	8.5	5	2.5	4
$M6$	6	10	6	3	5
$M8$	8	13	8	4	6
$M10$	10	16	10	5	8
$M12$	12	18	12	6	10

Fig.1 A bolt family

In interactive modelling processes, free-form surfaces can be changed by replacing the profile curves defining themselves. It is a very complex and time consuming job to replace the elements one by one. Usually, in practice, the CAD operators would prefer to model complicated free-form surfaces from the beginning rather than to replace or edit them. If the free-form surface portions are modeled separately and then united with the other features, the associativity of the whole part with its drawing can be broken and a rework with the drawing is needed.

Proposed in this paper is a new method for parametric design which generates a solid model and an engineering drawing for PFFSs.

A METHOD FOR DESIGN OF A PFFS

In the parametric modelling methods, a part in a family can be defined by a template of the family and a set of dimensions. The template model has a sequence of operations, all the input parameters and geometric elements. If the sequence of operations, parameters, or elements of a model is changed, the model is modified. Fig.2 illustrates this concept. A turbine blade model is completed by uniting a cover, airfoil, and rabbet by Boolean operations. The cover is defined by some dimensions, the airfoil is defined by some profiles, and the rabbet is defined by some dimensions and profiles. By changing the dimensions and replacing profiles a new model is generated.

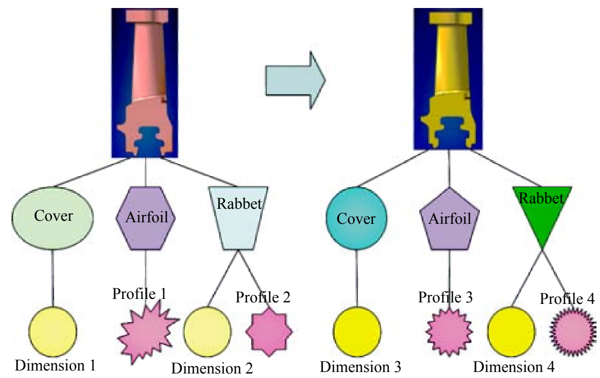


Fig.2 Generation of new model by replacing dimensions and profiles

Fig.3 shows an example of creating a new free-form surface from an existing surface by replacing eight old primary curves and two cross curves with five new primary and two new cross ones respectively. Note that an additional surface is not created, but the only shape of an existing surface is changed. Fig.4 (see page 1533) shows the airfoil models created with the input profiles in Fig.3.

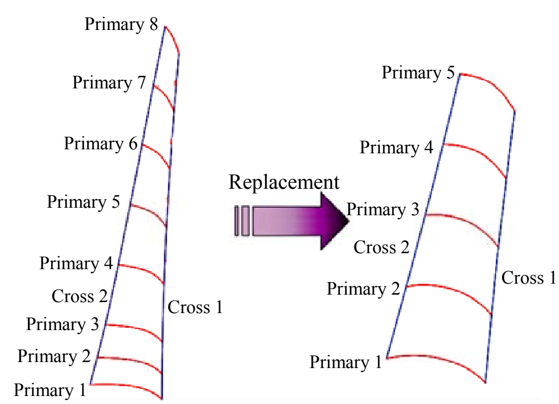


Fig.3 Creating a new surface from an existing surface

Two rabbets are shown in Fig.5 (see page 1533). The central serration portion is defined by a profile and some geometric operations. The shape is changed by replacing the profile curve.

Fig.6 shows the procedure of parametric design of PFFSs. The template model of PFFSs and a set of dimensions are input and the dimensions in the template are changed to the input dimensions. Then, new profiles are input and the existing profiles are replaced with new ones. In this process, some geometric analysis such as finding the number and directions of profiles is conducted. Finally the model is updated with new dimensions and new surfaces generated with the new profiles. The sequence of operations is kept in the procedure and the associativity of the model with the drawing is maintained.

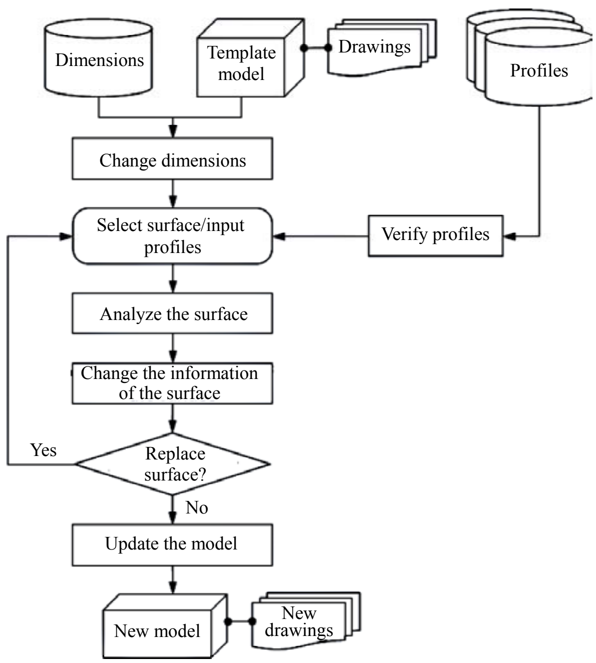


Fig.6 The procedure of parametric design of PFFSs

AN AUTOMATIC DESIGN SYSTEM FOR TURBINE BLADES

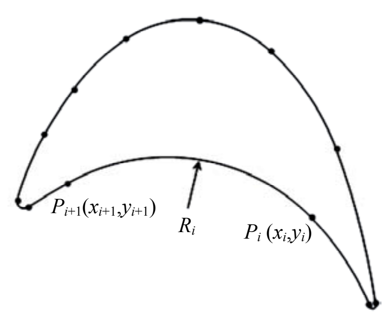
In the research an automated design system for turbine blades is developed based on the method introduced in Section 2.

The blade is one of the most import parts that affect the power and performance of a stream turbine generator. The blade is rotated by stream flow in the generator. This becomes motive power of the generator. One hundred fifty or more buckets are assembled circularly around at rotation axis, and we call it a 'stage'. There are 20 or more stages in the generator. A blade consists of an airfoil, a rabbet, and a cover portion. The airfoil meets steams flow and rotates. The rabbet is a portion that fits the blade to a rotor or turbine rotating shaft. When rotating, blades can undergo vibration. The cover reduces the vibration. Fig.7 (see page 1533) shows the various types of blades.

Preparing a template model and drawing

As shown in Fig.6, a template model is input for the parametric design system. First of all, template models for the rabbet, cover, and airfoil are prepared respectively. Fig.8 (see page 1533) shows the modelling process for the rabbet. The initial body of the rabbet is typically defined by parametric curves in a front view and a side view. The parametric curves have dimensions and geometric constraints. Some types of geometric constraints are horizontal, vertical, coincident, parallel, perpendicular, tangent, etc. The central serration portion is defined by profiles. The final rabbet model is obtained by subtracting the central serration from the initial body. The modelling process for the cover is similar to that of the rabbet.

An airfoil is defined by profiles curves, which are composed of arcs and line segments as shown in Fig.9. The airfoil is represented in a bicubic NURBS surface passing the profiles as shown in Fig.10 (see page 1533) (Piegl and Tiller, 1997).



Fig,9 A profile for an airfoil

The rabbet, cover, and airfoil models defined separately are united to the final turbine blade model by Boolean operations. After modelling the template model, the template drawing is prepared. The initial drawings are generated automatically from the model in most recent CAD tools. Adjusting layouts, dimensioning, and inserting annotations are required. Fig.11 (see page 1534) shows a portion of the final drawing.

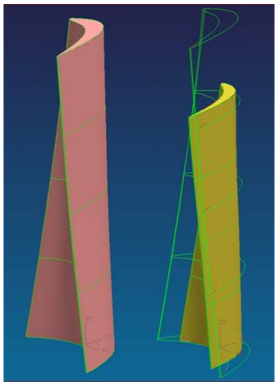


Fig.4 Airfoil models

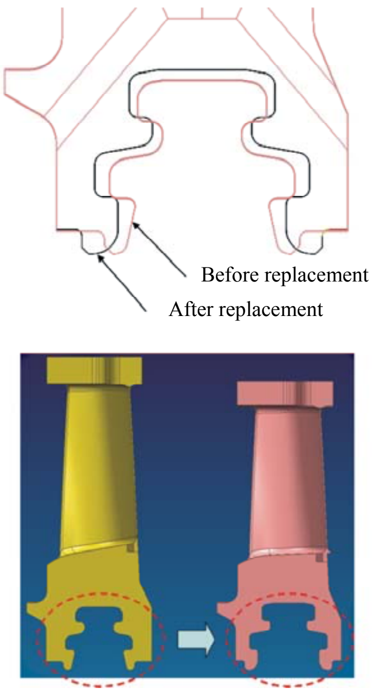


Fig.5 Rabbet models

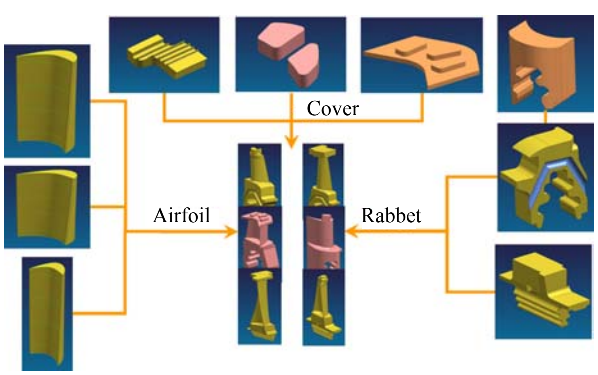


Fig.7 Turbine blades

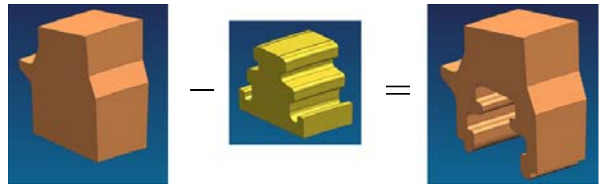


Fig.8 Modelling for a rabbet

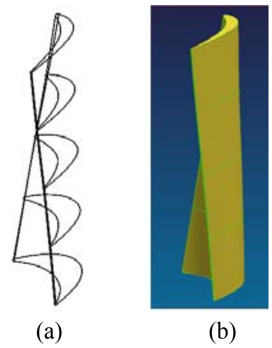


Fig.10 A 3D airfoil model. (a) Profiles; (b) Solid model

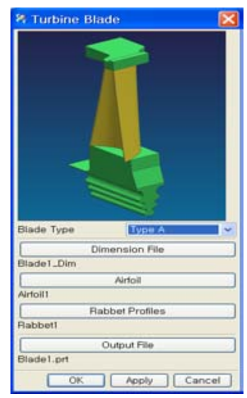


Fig.12 An input dialog box

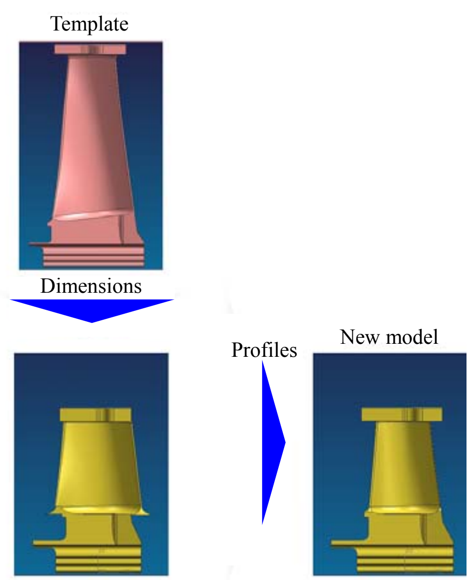


Fig.13 Creating a new blade

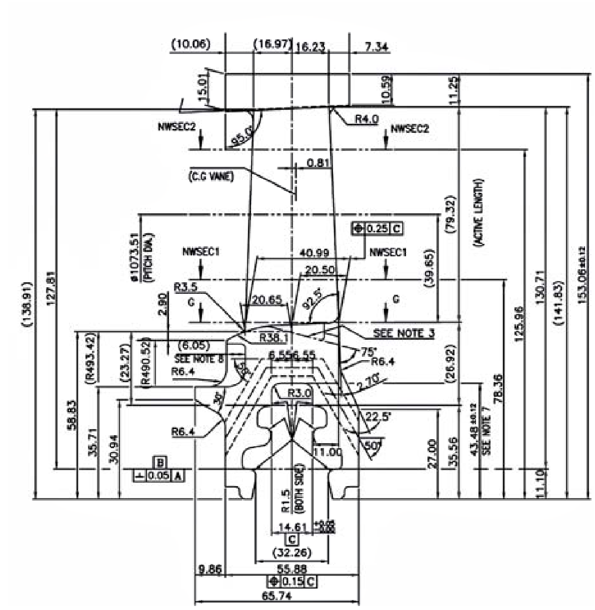


Fig.11 An example of drawing

Generating a new blade model

An input dialogue box is shown in Fig.12 (see page 1533). The inputs are a type of blade, a set of dimensions, and profiles for the airfoil and the rabbet are input. Fig.13 (see page 1533) illustrates the processes of creating a new model from the template: Changing dimensions and replacing the profiles.

CONCLUSION

A method for generating a solid model and drawing for PFFSs using profile replacement technique is proposed. The common (regular-form) surface portions are modeled by changing some dimensions of the template model. The free-form surface portions are obtained by replacing the old profile curves of the template with new profiles. With the proposed approach, the associativity between the 3D model and the drawing can be maintained completely, so the drawing is created automatically.

The proposed method has been implemented using a commercial CAD/CAM system, Unigraphics, and API functions written in C-language, and were applied to the blade of a steam turbine generator, shortened modelling time, and reduced the time for drawings.

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