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GIVING A TOOL-ORIENTATION TO MANUFACTURING FEATURES IN 2½-D COMPONENTS

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Described within this paper is a technique where manufacturing features in 2½-D components are associated with a given tool diameter. The components are stored in a boundary representation solid modeller. This procedure has been developed because there may be cases in which a given tool is not able to machine a feature completely. This procedure, called 'feature-splitting', can be considered as a post-processing feature-recognition algorithm, since it decides the volume that can be machined by a given tool. Finally, examples are presented, whereby the capability of the method can be realized.

INTRODUCTION

TECHMILL, a technologically oriented system for 2½-D components, is under development in the Mechanical Engineering Department at UMIST. It comprises five modules, which are: 1-geometry; 2-operations planning; 3-tool selection; 4-cutting technology and 5-post processing [1]. Given the component, the blank, the tools and machine tools available, the ultimate aim of the system is to generate the part program to machine the component with minimum human intervention. The 2½-D components are stored in a boundary representation solid modeller.

Two of the programs that have been developed and are part of the geometry module of TECHMILL are: *feature-recognition* and *feature-splitting* [2]. The feature-recognition program consists of grouping topological and geometrical information such as faces, edges, surfaces and curves, into feature information, such as holes, slots and pockets. The technique presented in [3] is used in TECHMILL as a means to recognize features.

After the recognition is completed, the features are input to the feature-splitting program together with a value for the cutter diameter given by the user. The feature-splitting program determines the volume of each feature that the given tool can machine and also the volume that it cannot machine (see Figure 1).

Two reasons have contributed to the development of the feature-splitting program. They are:
(a) Some features are merged into one single feature by the feature-recognizer (see reference [3]), as a result of which a given tool may not be able to machine the feature completely;
(b) The most cost effective process plan may be achieved by using multiple tools, even for a simple feature. For example, a tool with a big diameter may be used to open a rectangular pocket, and the remaining material may be machined by a tool having a smaller diameter.

The first reason makes the feature-splitting technique to be a post-processor for the feature-recognition method, in which the tool diameter is taken into account in the analysis of the feature. At the same time, this procedure is a front-end to programs

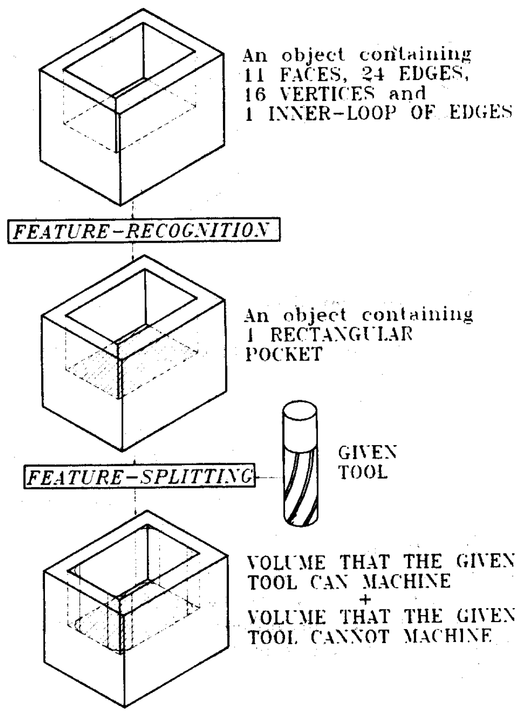


Figure 1. The role played by the programs for feature-recognition and feature-splitting.

such as tool path generation, in which material that a certain tool cannot machine is not considered.

In this paper, the feature-splitting technique is described, and two examples are given in order to illustrate the capability of the method.

PREVIOUS WORK

Feature-recognition is a very important means to achieve the goal of process planning, and therefore much research work has been devoted towards automatic feature-recognition. Some examples of relevant work on this area are the ones developed by Kyprianou [4], Choi [5], Henderson and Anderson [6], Joshi and Chang [7] and Ferreira and Hinduja [3]. However, no work has been found in the literature by the authors which associates a recognized feature with a certain tool diameter.

Since the feature-recognition method developed in [3] is used in TECHMILL, the most important aspects of this technique are summarized below.

FEATURE-RECOGNITION

A feature is defined in [3] as "the amount of material that has to be machined". From this definition, assuming that the blank is equal to the minimum volume that encloses the component, three entities may give rise to features, as shown in Figure 2. These entities are a *concave face*, an *inner-loop of edges* and a *concave edge*. The feature-recognition method checks for the presence of each of these entities in the component.

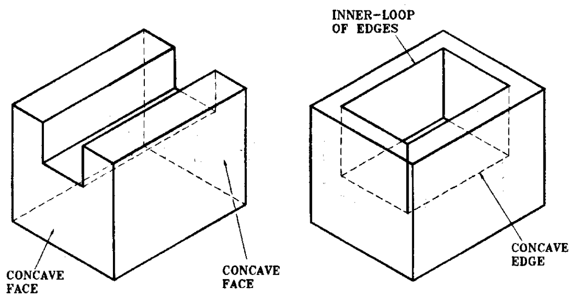


Figure 2. Entities that give rise to features.

The most important achievements of the feature-recognition algorithm are as follows:
(a) the directions of approach and the machining depths for each feature are determined;
(b) the features are given names, so that the automation of process planning is attained;
(c) up to two arrangements of features are output. This is done because without performing cost calculations including the tools and machine tools available, it is difficult to ascertain which arrangement of features is more suitable for machining.

Since this method outputs information which is important for the determination of machining operations, it can be part of an automated process planning system.

THE FEATURE-SPLITTING ALGORITHM

The features which are output by the feature-recognizer need to be linked with other geometric modules of TECHMILL such as tool path generation. However, a given tool may not be able to machine a feature completely. For example, a cutter diameter may be bigger than the fillet diameter of a pocket. Hence there is a need to implement a technique for calculating the material that can be machined with a given cutter. A description of a method developed for that purpose is given below.

Since the components being dealt with are 2½-D, the base surface of each feature is analysed rather than the whole volume. This facilitates the solution of the problem, which becomes two-dimensional. The base surface of the feature is represented by a *lamina*, which is a two-sided Euler object with no thickness. This lamina is formed by intersecting the base surface of the feature with the *entry surfaces* and the *restriction faces* of the feature. An entry surface is the name given to the possible directions of approach for the cutter to machine a feature, and a restriction face is a face that comprises a feature. The edges that form the lamina are therefore called "entry" and "restriction" edges (see Figure 3).

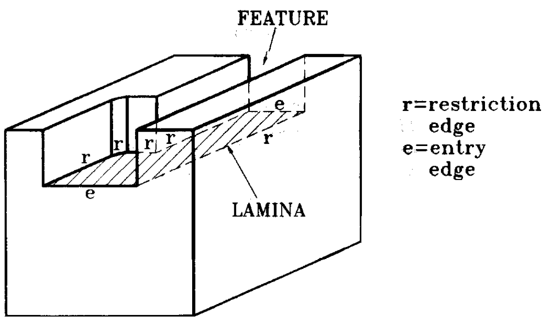


Figure 3. Lamina representing the base surface of a feature.

The present implementation of the feature-splitting program caters for straight lines and arcs of circles, which corresponds to a large amount of the components commonly found in industry.

The feature-splitting procedure consists of traversing clockwisely the edges which belong to the lamina representing the feature. When an edge is analysed, it is referred to as the "drive edge". For each drive edge, the circle that represents the cutter is positioned tangent to the curve where the edge lies, touching the start vertex first, and then the end vertex, as shown in Figure 4(a). When a vertex is tangent to the tool, it is called "touching vertex".

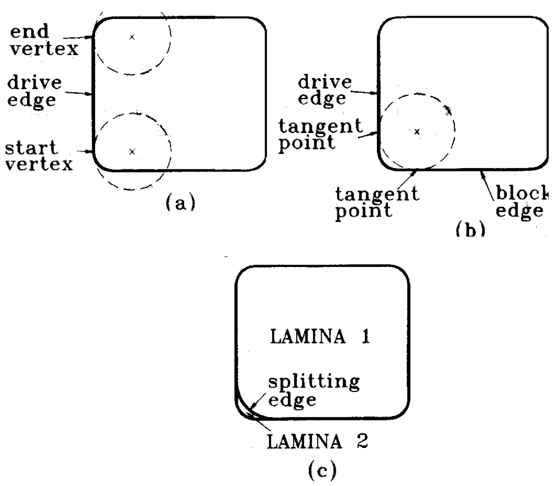


Figure 4. The first movement of the tool

The cutter at each of these positions is intersected with all the restriction edges of the lamina. If there are no intersections, the next edge becomes the drive edge. If an intersection exists, the tool is moved in order to determine a position where there is no intersection. During this process, which is called 'splitting search', the tool may perform up to three different movements. One movement is applied at a time, and depending on the results of each movement, either the lamina is split into two laminae or the next movement is applied to the tool. The description of these movements is given below.

Movement 1. First, the edge that intersects the cutter is determined, which is called "block edge". Then, the cutter is translated along the curve where the drive edge lies, called "drive curve", until it becomes tangent to the "block curve". The tangent points to the drive and block curves must lie on the drive and block edges respectively. After this tangent position is determined, as shown in Figure 4(b), the cutter is once again intersected with the restriction edges of the lamina. If no intersection is encountered, the lamina is split by a circular edge connecting the tangent points on the drive and block edges, centered at the new centre-point, as shown in Figure 4(c). If the cutter still intersects the edges of the lamina, the second movement is applied to the tool.

Movement 2. First, the edge meeting at the touching vertex of the drive edge is determined, which is referred to as the "auxiliar edge". Then the cutter is translated until it becomes tangent to the block and auxiliar curves, as shown in Figure 5(a). If the tangent point between the tool and the block curve lies on the block edge, and if the tool at this new position does not intersect the restriction edges of the lamina, the lamina is split by two edges, one being linear and the other being circular, as shown in Figure 5(b). If the tangent point between the tool and the block curve does not lie on the block edge, or if there is an intersection between the tool and the edges of the lamina, the third movement is applied to the tool.

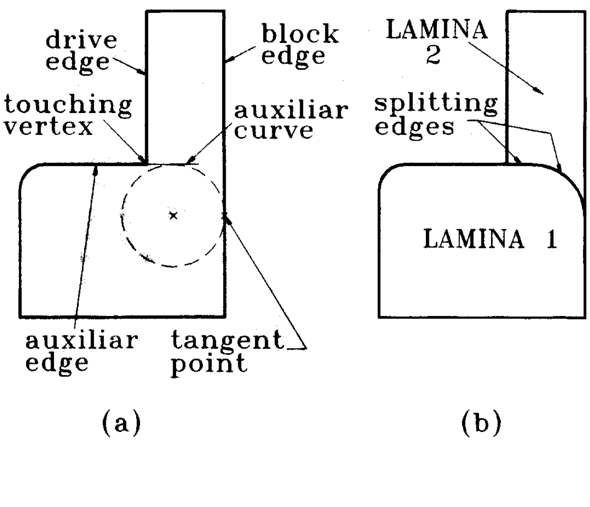


Figure 5. The second movement of the tool.

Movement 3. The tool is rotated around the touching vertex until it becomes tangent to the block curve, as shown in Figure 6(a). Depending on the results of this rotation, the lamina may be split in two different ways, as explained below.
(a) if the tangent point between the tool and the block curve lies on the block edge, and if no intersection is found between the tool and the restriction edges of the lamina, the lamina is split by a circular edge connecting the touching vertex to the tangent point on the block edge, as shown in Figure 6(b).

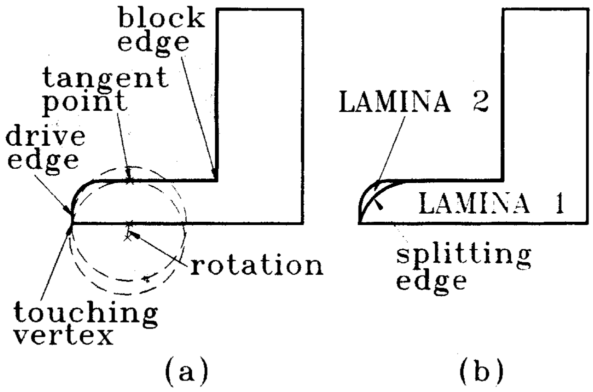


Figure 6. The third movement of the tool, leading to the lamina being split by a circular edge.

(b) if the tangent point between the tool and the block curve lies outside the block edge, and if no intersection between the tool and the edges of the lamina has been found, the lamina is split by a linear edge connecting the touching vertex to the vertex on the block edge which is nearest to the touching vertex. An example of this situation is given in Figure 7.

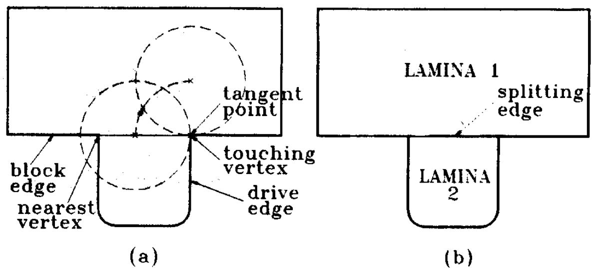
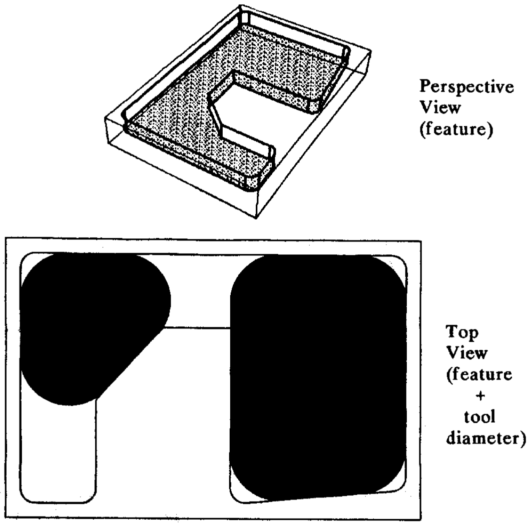


Figure 7. The third movement of the tool, leading to the lamina being split by a linear edge.

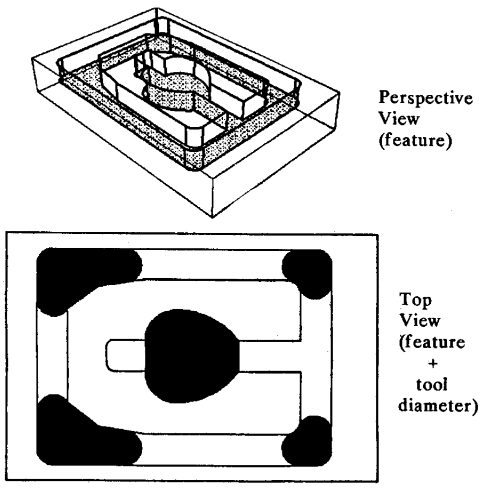
EXAMPLES

The feature-splitting method has been applied to two general pockets, and the results are shown in Figure 8. The material that can be machined by the tool is given by the area shown in black.

The lamina representing the pocket shown in Figure 8(a) contains nine linear edges and six circular edges. The output shown in the figure corresponds to a tool diameter equal to 65mm, and the CPU time spent by the feature-splitting method was 1.98 seconds.



(a) First example



(b) Second example

Figure 8. The feature-splitting method applied to two general pockets.

As a second example, the pocket shown in Figure 8(b) is considered. Notice that an island originates from the base surface of the pocket. The lamina representing this feature contains 18 linear edges and 12 circular edges. The output shown in the figure corresponds to a tool diameter equal to 22mm, and the CPU time spent by this procedure was 4.20 seconds.

CONCLUSIONS

It should be emphasized that the feature-splitting algorithm described above can be applied to any 2½-D manufacturing feature, provided the component is stored in a boundary representation solid modeller, and the entry surfaces and restriction faces of each feature are given.

The feature-splitting program, by associating a given tool with the material that it can machine, becomes a very important contribution to programs such as tool selection and tool path generation, which therefore leads to a reduction in the cutting cost.

The feature-recognition and feature-splitting programs enable the calculation of the cost for various cutters to machine different arrangements of features, ensuring that the combination of tools and volumes is such that the cost of machining will be a minimum.

EQUIPMENT USED

The solid modeller used is "Geometric Product Models", G.P.M. [8], which was developed in FORTRAN IV. The complete system currently runs on Sun Microsystems 3/50M (monochrome) and 3/110LC (colour) workstations, which are connected to a Sun Server 3/280S. The graphics package which is used for drawing the objects is SunCore, and the operating system is UNIX. As output device, an Apple LaserWriter is used.

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