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Feature Models in Virtual Product Development

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The development of new products requires the use of modern tools for design, which make the evasion of errors and the reduction of the number of iterations possible even in the early phases of development. In the concept of simultaneous development of products and technologies, feature-based design enables the creation of product models suitable for various engineering applications. The paper provides an outline of the favorable effects of feature-based design during the development of a virtual product in a digital factory environment. What is emphasized is the manufacturability analysis, which facilitates the adaption of the product to manufacturing conditions and the reduction of manufacturing costs.

Keywords: feature-based design, manufacturability analysis, design for manufacturing, intelligent CAD systems, simultaneous design

0 INTRODUCTION

The basic precondition for the development of every country is to maintain the existing market and, if possible, expand it. In order to do so, it is necessary to keep meeting the demands of the market over a number of years. The market permanently sets even more complex demands, regarding the manufacturability, quality, and speed of development of new products. Therefore, what is required is knowledge, learning, which creates good receptiveness to innovations, new economic and technical solutions, and readiness to meet the individual demands of customers in a highly competitive market.

Nowadays, the situation in the world market is characterized by two tendencies [1]:

- domination of customers' demands,
- globalization of the market.

The domination of customers' demands means that modern products must satisfy the customers' expectations and needs, down to the level of their individual requirements, which gives rise to product differentiation and permanent innovation.

The globalization of the market increases competition, so it is of high importance to quickly launch various quality products. The demands which modern manufacturing meets can best be seen in an analysis of changes in companies, performed between 1990 and 2000. The time of product delivery was reduced by 60%, demands regarding product quality and functionality were increased by 50%, with a parallel increase of competition in the market (by approximately 50%), which in some cases radically reduced product cost. Within this period, the lifetime of products was reduced by around 20% [2].

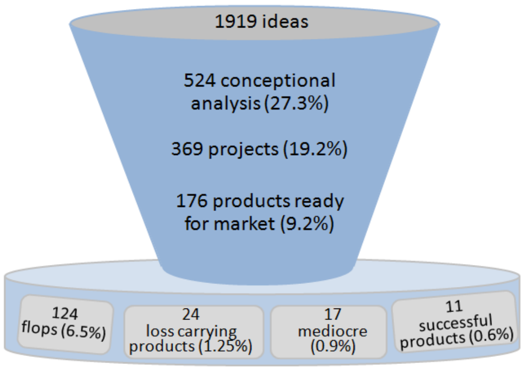

Fig. 1. *Less than 1% of ideas become innovation*

Nowadays, it is necessary to consider market needs, customer wishes, competition, enterprise development and manufacturing capabilities and draw conclusions from these considerations in order to define the proper product profile. The study by Berth [3] (Fig.1) shows that the percent of success in development of innovative products, processes and services, is actually very low. Less than 3% of development projects result in innovative products. Moreover, only fractions of the ideas generated in the idea finding process are actually successful in the market (less than 1%).

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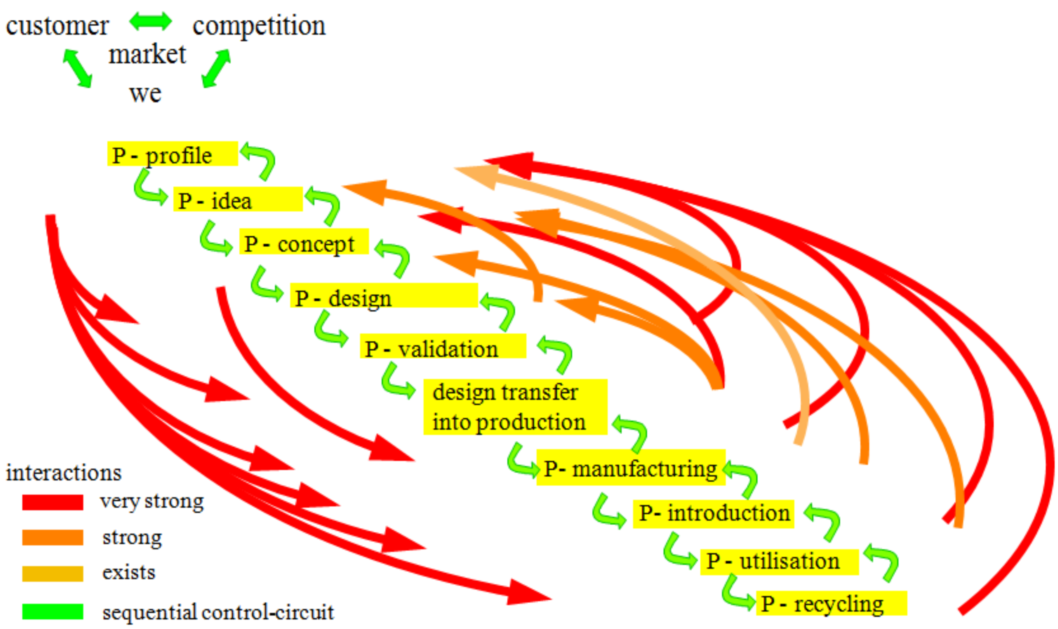

Fig. 2. *Process of product development, realization and utilization*

The introduction of innovative products, processes and services is very complex and demands application of integrated development approaches, which rely on up-to-date development methods, processes and systems. In comparison to the conventional approach, the integrated product development is based on interdisciplinary project teams, methodical work approach, parallel process structure of certain product development phases (simulation engineering) and usage of modern information technologies. This approach influences the shortening of time for the designing and introduction of new products (time to market), the reduction of prices (design to cost) and the increase of product quality (best quality).

Due to the strong need of reducing the time to market, the Product Development Process (PDP) is often no longer a series of isolated steps. The more complex a technical system and the more people working on its development, the more steps begin to overlap: for example, the function of the whole system has to be validated even before the last details are designed.

On the other hand, each process of the PDP can affect the later steps as well as the earlier ones. These correlations are visualized in Fig. 2: all of the decisions made during the design of a product are influenced by other steps.

For instance, the expected shape of a product has a strong influence on its manufacturing process. Also vice versa, the manufacturing process can have an influence on the earlier phases of the PDP. Usually, a designer will change his first idea of the shape of a product with respect to the costs of the manufacturing process [4] and [5].

Computer backup is essential to all phases of the product development process and manufacturing. Since the 80's, the constant growth in application of computer aided (CA) tools in product development and manufacturing processes has been obvious. Modern software systems integrate existing CA tools into systems for product development and its lifecycle management.

These tools define a virtual product as a computer model of the realistic product and support the many interdependent processes required to bring innovative products to market.

Virtual product model include the entire range of information generated and used in PDP and provide a link between different disciplines and groups such as design, manufacturing, marketing etc. [6].

1 PRODUCT DEVELOPMENT USING FEATURE-BASED DESIGN

The design process describes a product in detail, from the initial idea to gaining grounds for its manufacturing. To meet all demands, changes in design are frequently required, e.g. results of FEM or BEM calculations may require change in the object of design. Such changes can be supported by applying intelligent systems [7] or feature-based design, where geometry is modeled through changeable parameters.

It is in the phase of sketch creation, when the geometry has not yet been worked out in detail, that translation of functional dependencies into geometrical measures is performed. This is why contours and surface elements are defined through changeable parameters, and interconnected by means of a number of relations [8].

Procedures of design, i.e. modeling, are most frequently based on composing geometrical primitives. Such an approach frequently provides only a conceptual design of the structure. It is often the case that the designer needs to think about the product's function and to predict its manufacturing procedures. Upconstruction and extending of geometrical primitives by structural and technological forms is known as feature-based design, which enables more flexible work on product development.

Features help computer-based elaboration of the designing task. The information which they contain is used in all phases of product development, so they represent the basis for a methodological approach to product development. A feature consists of the semantic and geometrical part. A *form-feature* represents a set of geometrical features. Such a geometrical object can be composed of a group of features relating to contours, surfaces, volumes, or parts, combined according to demands. This can be exemplified by the shaft-wheel centre constraint, where there is an adequate combination of grooves and holes. These objects contain the required geometrical information. As opposed to this, *semantics* contains non-geometrical information [9], e.g. structure-related or technological data. Feature semantic information can be described through three types of attributes:

- static, technological attributes, such as tolerances of shape and position, and machining allowance,
- parameters for corresponding geometrical values, such as length of holes and standard screw diameter,
- functional and technological constraints, such as rules about the complete feature structuring of parts or assemblies.

In this way, a feature can contain semantic information related to the shape, which also provides a description of the purpose of application. Distinction should be made between features relating to structure, manufacturing, or quality. The designer has the option to work with structural features, whose informational content also includes the following processes, e.g. those which refer to NC-programming.

In contrast to conventional design technology, which frequently deals solely with geometrical parameters, the designer here also has semantic contents of the design object at his disposal. At any moment, he or she can redefine or change the structure, e.g. if the manufacturing procedure of the object changes, which affects the quality of surfaces. In this case, a special feature-library is available; the user can access it at all times [8].

With the introduction of the feature as a semantic object in the system of product development, the information surpassing the geometrical description of a product can be processed. Informational contents of a feature are oriented towards semantic parameters, which are of high importance to users (Fig. 3).

According to the way in which they are created, feature-based models can be divided into three groups: the feature-based models that are created by

- interactive feature definition,
- automatic feature recognition,
- design by features.

2 DESIGN BY FEATURES

Design by features implements features in the designing process, where the model of a product itself contains geometrical, topological, and semantic information (Fig. 4). Apart from

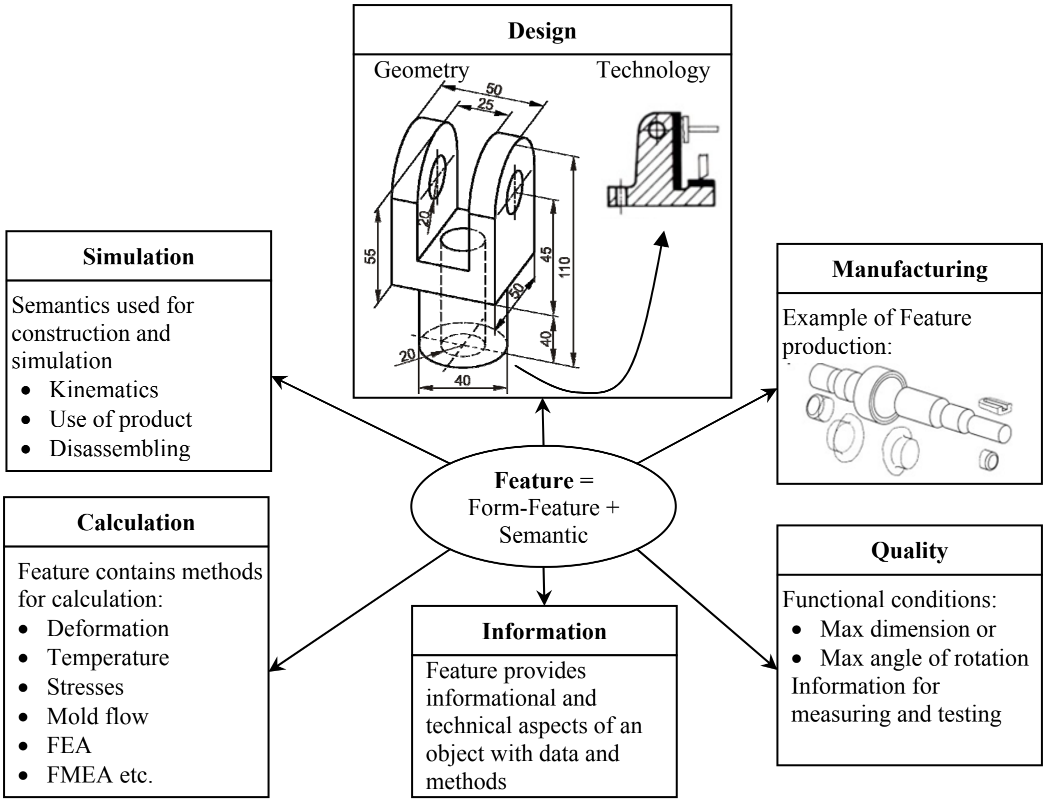

Fig. 3. *User aspect of a feature*

determining the geometry and the topology, models that are designed by features also give the designer more freedom regarding the shaping of the structure. Through feature-related semantics, information, rules and functional dependencies can be processed and stored in a computer, so that they can be used in the later development of the system.

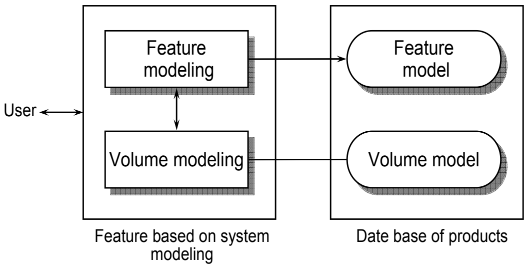

Fig. 4. *Design by Feature*

Design by features consists of three parts:

- design, supported by a pre-defined, programmed feature,
- design with an implicit feature (e.g. standard design elements like thread, etc.),
- design through the use of a feature, memorized explicitly in the model and implicitly in the manufacturing procedure.

3 DESIGN BY COMBINING FEATURES

The technique of model design by combining features is to a large extent adapted to the engineer's logic. Within this technique, structural or technological features modeled through sketches or pick-and-place procedure (pre-defined, such as holes, rounds, chamfers, drafts etc.) are added to a usually simple base feature (Fig. 5). Apart from the definition of geometry and constraints, the description of features also contains the definition of the behavior of geometry through rules and attributes [8]. They represent some of the structural and technological geometrical shapes which are most frequently met in practice. The design shapes have positive volume and are obtained by some of the described techniques: on the basis of 2D contours or by combining primitives, whereas technological shapes have negative volume.

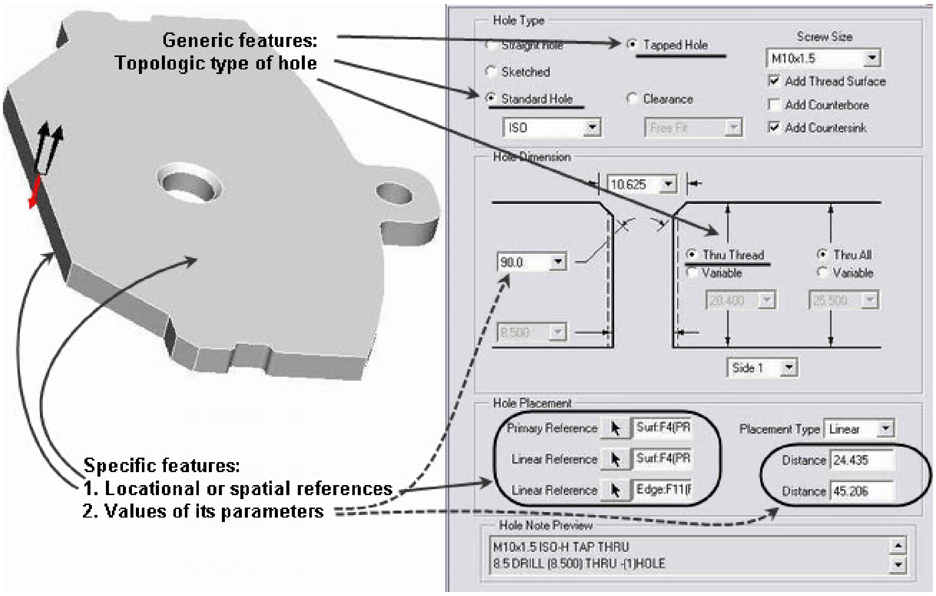

Fig. 5. *Technical element hole with its properties*

These are holes, rounded and chamfered edges, grooves, etc. Dimensional parameters of the features themselves and dimensional parameters of their position in relation to the 3D model are changeable.

From the standpoint of the engineer's logic, what is of special importance is the fact that features have certain 'intelligence', which enables them to maintain their interrelationship under change. In addition, it is possible to define the so-called *user-defined features* (UDF). A UDF could, for example, be a hole with a thread or a complex groove. Once created, a UDF can be used in further work as a unique feature. Fig. 6 shows the generic UDF of the lateral groove at the tire tread pattern with constraints and referenced technology.

By using Feature Based Design together with library forms and UDF, a product model can be created and then, through various computer-aided product development techniques, analyzed so that it becomes a virtual prototype.

4 MANUFACTURABILITY ANALYSIS BY USING FEATURE-BASED DESIGN

Manufacturability analysis has become an important part of modern CAD/CAPP/CAM systems. Unintentional errors, such as omission of rounding-off of the edges or unreasonably high demands with respect to the quality of certain surfaces, which would otherwise emerge from the design phase, can be evaded by the implementation of the design-for-manufacturing tools.

The most frequent problems considered in relation to the virtual prototype manufacturability analysis comprise the following three analyses [9] to [12]:

1. Determining whether a virtual prototype (shape, dimensions, tolerances, surface quality) is manufacturable or not;
2. If a virtual prototype is manufacturable, determining the degree of manufacturability;
3. If a virtual prototype is not manufacturable, recognizing the properties which create problems during manufacture.

In manufacturability analysis, there are three primary characteristics according to which systems are classified. These are: approaches to consideration of manufacturability, measures for determining the degree of manufacturability, and the degree of automation.

Approaches to the analysis of structure manufacturability can be roughly classified in the following way [13]. First comes the *direct approach*, or the approach based on the use of rules which directly inspect the geometrical model, i.e. features. This is convenient when dealing with parts that require just finishing, such as casting, forging, sintering etc. The second is the *indirect approach*, based on the use of the manufacturing procedure. In the first step, the manufacturing procedure is defined, then analyzed and reduced so as to cut the expenses. If there are several alternatives, the optimal one is selected. This approach is more applicable than direct approach.

Measures for determining the degree of manufacturability are the following: *binary assessment,* i.e. whether something can be done or not, *qualitative assessment* of a virtual prototype within a manufacturing procedure, which assesses the degree of manufacturability as low, average, good, or highly manufacturable, and *abstract-quantitative assessment* of the degree of manufacturability, which is performed by attributing numerical values to a procedure from a selected range of the numerical scale. As measures of manufacturability, there also appear *time* and *expenses* required for the manufacture of a certain type of construction, which can be combined into a total of manufacturability.

The degree of automation of a system for manufacturability analysis is expressed in the way in which the designer interacts with the system. It is measured by the quantity and type of the designer's interactions with the system, and by the quantity and type of feedback from the system.

Qualitative technological analyses usually make use of features, together with the technological database. They usually consider the following questions:

- Which machining processes are required for the manufacture of a designed prototype?
- Are all of the required manufacturing resources (material, machines, tools, fixtures etc.) available, and under which conditions?
- Is it physically possible to apply all of the required machining processes?
- Are all of the determined technological parameters in accordance with the acquired and established manufacturing experiences?

Qualitative analyses contain rules based on technological knowledge and experience. Most frequently, production rules of IF-THEN type are used [15]. For example, the following rule determines the machining sequence procedure that is required for hole production in relation to the technological features of a hole:

IF *feature FEAT_ID2.TYPE = HOLE*
/ If the selected feature is a hole*
AND *FEAT_ID2.D=[10,30]*
**/ diameter of the hole is from 10 to 30 mm*
AND *FEAT_ID2.SURF.Ra* $\leq 1,6$
**/ the roughness of hole surface is smaller or equal than 1,6 µm*
OR *FEAT_ID2.D.T1=[IT8,IT9]*
**/ tolerance of the diameter is IT8 or IT9*
THEN *FEAT_ID2.MFGSEQ = (CENTERING, DRILLING, BORING, REAMING)*
/ The hole should be machined by following mfg-sequences: centering, drilling, boring and reaming.*

5 FEATURES IN CAM APPLICATIONS – TECHNOLOGICAL FEATURES

For applications dealing with designing the manufacturing process, features must be defined in a form which enables planning and performing various types of manufacturing (technological) processes on a product model.

A technological feature is usually defined as a set of related geometrical elements, which, as a whole, corresponds to the concrete technological process required for their manufacturing (Fig. 8), or which can be used in the process of determining which technological process is required for their manufacturing [16].

The connection between features and technological information is usually realized through the model of the technological process [17]. In typical cases of machining, models of

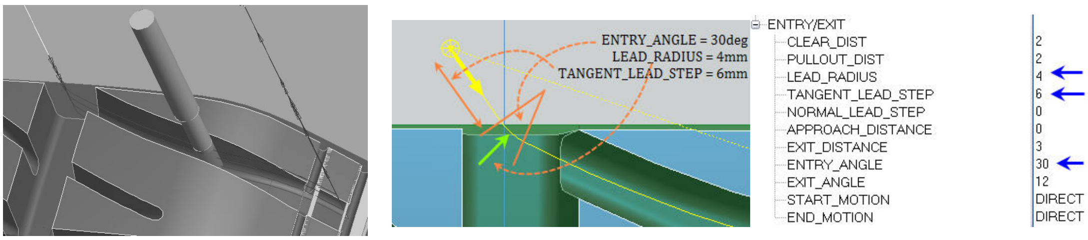

Fig. 6. *The geometry of lateral groove at tire tread and referenced manufacturing information*

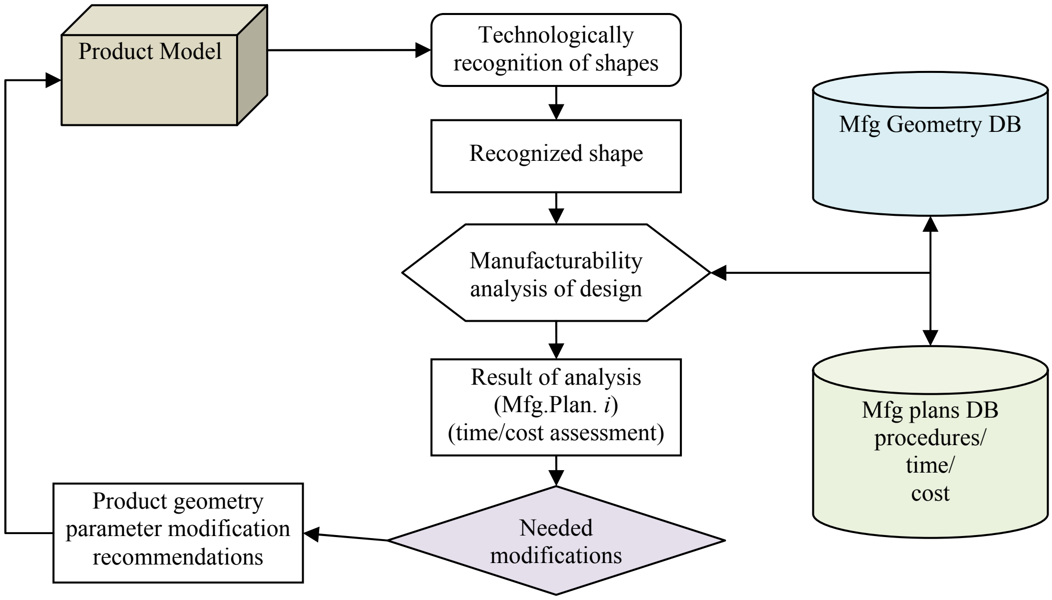

Fig. 7. *Technological analysis in product development* [14] and [15]

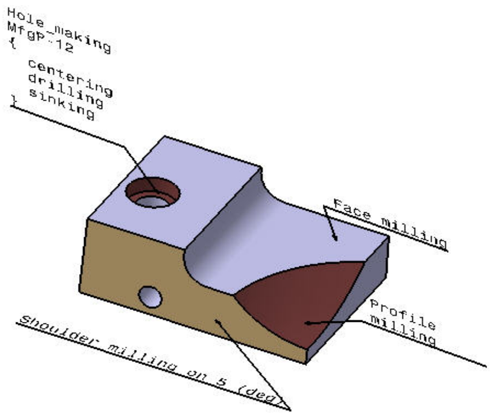

Fig. 8. *Each geometrical feature of a product corresponds to an appropriate manufacturing process*

technological processes can be organized as sets of elementary machining processes, such as milling, drilling, turning etc.

Models of the technological process are expressed within the informational model of manufacturing resources, which can be used to conduct machining processes (machine tools, tools, clamping devices, accessory materials). Technological process parameters have to do with the possibilities of these resources, whereas information about the so-called remaining attributes determines the selection of a concrete process (cost, time etc.).

To implement the connection between technical and technological features, technological features are represented by sets of possible models of technological processes which can be applied to manufacture a technical feature. For example, if we need to manufacture a feature with prismatic machining volume (the first figure in Table 1), this feature is connected with models of alternative technological milling methods which can be applied. In this case, the term 'method' is used to mark a type of NC sequence of the process for feature manufacturing. As shown in Table 1, methods can contain knowledge about planning the technological procedure but also procedures for costs and time evaluation.

6 CONCLUSION

The following conclusions can be made on the basis of this discussion:

- A consequence of the globalization of the market is a manifold increase in competition. In order for companies to survive in the market under such conditions, the reduction of the time required for product development, improvement of product quality, and the reduction of product price are imperative. The

Table 1. *Technical elements in CAM application*

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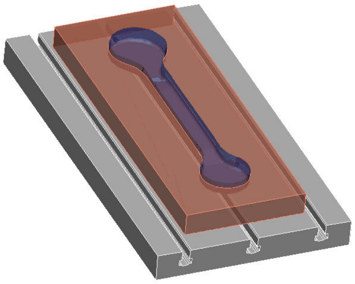
<tr><td></td><td colspan="2">|***|
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|***|
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Date   : 20-Jul-08 13:54:43
|***|
| NC Sequence Number : 1 |
|***|
Feature ID   : 1521
Feature Number : 14
Operation Name : OP010
Workcell Name : HAAS_VF-1
Workcell Type : Mill
Sequence Type : Volume Milling
Cut Mtn Feat   : 1715
Axis Type   : 3 Axis
Fixture Setup : FSETP0
Mill Volume   : MILL_VOL_1
Tool ID   : T0001
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Retract Plane : RP
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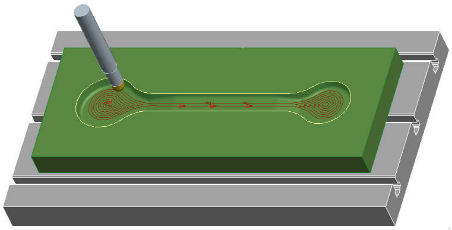
<tr><td></td><td colspan="2">|-------------------------|
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|-------------------------|
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NCL_FILE -
PRE_MACHINING_FILE -
POST_MACHINING_FILE -
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SCAN_TYPE FOLLOW_HARDWALLS
CUT_TYPE CLIMB
STEPOVER_ADJUST YES
RETRACT_OPTION SMART
RETRACT_TRANSITION CORNER_TRANSITION
TRIM_TO_WORKPIECE TRIM_TO_TOP
CUT_DIRECTION STANDARD
CORNER_FINISH_TYPE FILLET
CUSTOMIZE_AUTO_RETRACT YES
POCKET_EXTEND TOOL_ON
PLUNGE_PREVIOUS NO
STEP_DEPTH 6
MIN_STEP_DEPTH -
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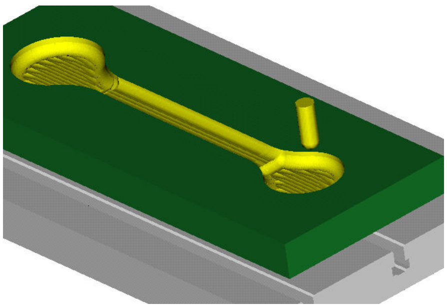
STEP_OVER 4</td></tr>
<tr><td></td><td>$$* Pro/CLfile Version Wildfire 3.0 - M090
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UNITS / MM
LOADTL / 2
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$$-> CSYS / 1.0000000000, 0.0000000000, 0.0000000000, 0.0000000000, $
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RAPID
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X3.965Y109.46Z12.215
X4.Y110.027Z11.881
X3.954Y110.593Z11.635
X3.829Y111.147Z11.463
X3.627Y111.677Z11.313
X3.352Y112.173Z11.166
X3.009Y112.626Z11.022
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solution lies in finding and applying a global strategy for product development.

- One of the global development strategies, which has yielded good results in practice, is the integral product development. The efficiency of applying this strategy is primarily based on the simultaneous management of phases in the process of product development, the application of an integral organization model, as well as the application of an all-encompassing and forced computer support of all activities in product development.
- Modern product development requires making manufacturing decisions as early as in the phase of product design. Successful solutions of these problems are reached by using features during product design and analysis, bearing in mind that, by their definition, they can be technologically recognized and analyzed. In the intelligent CAD system concept, design for manufacturing is implemented by applying automated manufacturability analyses based on technological knowledge incorporated into the system. The presented methodology enables the realization of simultaneous design and development of a product within integrated CAD/CAPP/CAM systems.

7 ACKNOWLEDGEMENTS

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