A Feature Based Design (FBD) Method Embedded with Design for Manufacturing (DFM) Capability

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Abstract. *The objective of this paper is to present a DFM - Design for Manufacturing - method based on the DBF - Design by Features concept, specially designed to fulfill the industrial requirement of promoting the design - manufacturing integration in a simple, quick and efficient manner. This investigation has received support from a heavy construction company as the proposed method has been used into real cases within the company.*

Keywords*: Design for Manufacturing, Design by Features, Manufacture Tools*

1. Introduction

In the present globalization scenario, companies in general have been trying to reduce the manufacturing lead time, to improve the product quality as well as to reduce the development costs, to become consequently more competitive. One of the ideas to achieve this goal it to promote the integration among the several areas involved in the product development process. This is the core of the Concurrent Engineering practice that tries to overcome the problems raised by the professional or physical barriers among the technical areas within a company. The Concurrent Engineering practice is based on multidisciplinary teams and several tools or methods [Nevins and Whitney, 1989] which allow people of several technical backgrounds to exchange information related to different phases of the product development cycle. As a consequence, problems which would be faced later are anticipated and solved at the conceptual phase of the product development process where the modifications are easy and cheap to implement. Nowadays, the tools available to assist the Concurrent Engineering practice are: Axiomatic Design, DFA - Design for Assembly [Boothroyd and Dewhurst, 1983], DFM - Design for Manufacturing [Corbet et al., 1991], Taguchi`s Robust Design [Ross, 1998], Group Technology [Mitsutani, 1990], Value Engineering, Design for Logistics and QFD – Quality Function Deployment, among others. This paper proposes a typical Concurrent Engineering method derived from two other ones, namely Design for Manufacturing (DFM) and Design by Features (DBF). The method has been tested in an industrial design environment with encouraging preliminary results.

2. The Proposed Method

As this work is more closely related with the DFM and DBF methods, these are quickly reviewed herein as a background for the presentation of the proposed method.

2.1 DFM:

In a wilder sense, DFM - Design for Manufacturing is concerned with the understanding of the interactions between product design and the several areas of the manufacturing system which are affect by the design process. The importance of the manufacturability in the product design process has been recognized in years, since 80% or more of the production decisions are directly determined in the conceptual phase of the product development process, which leaves few possible choices for the process planning phase [Bedworth, 1991].

Many DFM principles are rooted in the history of the design and manufacturing interaction. Many have been learned empirically. So much that the DFM - Design for Manufacturing methods are being used by industries and universities for the last 20 years with mixed results. Some companies claim that they are useful and brought good results. Bad results, unfortunately, have also been reported. One of the main difficulties for applying the DFM methods posed by industrial design teams is that their usage is not straightforward or simple. It requires a lot of training and engineers are required to leave their daily environment for using the method.

The DFM principles listed below illustrate its comprehensive nature and provide the understanding on how they can be used to help the product development teams. These are:

- Reduce the number of parts;
- Use modular design reduces the number of the parts being assembled;
- Use standards components to reduce cost;

- Reduce, simplify, and optimize manufacturing process;
- Eliminate fasteners;
- Work on a minimum number of surfaces;
- Do not fight gravity;
- Optimize the handling of the parts.

2.2 DBF:

An important process in the integration of the CAD/CAM systems for manufacturing automation is to link up the topological and/or geometrical data and the manufacturing data. To accomplish this task, it is necessary to generate the appropriate machining information from a CAD model. The usage of features has been considered to be the technology which bridges the gap between CAD and CAM within an integrated environment [Wong, 1994].

Therefore, features should contain geometrical and technological information as well as the manufacturing semantics. However, the majority of current feature based applications are concentrated on the description of the geometry and form of a component. These particular kinds of features are called form-features.

Form-features are, in general, classified into design features and manufacturing features, though some design features can also be manufacturing features as well as inspection features. From the design point of view, a design feature is a functional feature which encompasses mainly geometrical details. For instance, simple mechanical parts may be described by a set of features such as hole, slot and pocket. From the point of view of manufacturing, features can be used to represent shapes which are of significance process planning and manufacturing.

In respect to CAD/CAM integration, there are mainly two approaches for using form-features, that is, feature recognition and feature based design. In the former, the application features are automatically or interactively recognized from a geometrical model of the object; in the latter, a product model can be built by using pre-defined features.

Using the feature recognition approach, design can be carried out using conventional CAD systems. However, feature recognition requires that each feature has a pre-defined pattern primitive or rule-based template, and only a limited number of features can be recognized. Besides, the present matching process is tedious and complex. By comparison, the approach of feature based design is easier and simpler to work with. The feature based design approach, also known as design-by-feature or feature-based modeling, provides the designer with a set of features in a feature library. A designer, applying the appropriate modeling operators such as the Boolean set operators in the CSG – Constructive Solid Geometry - solid modelers, can then build the product model with all the pre-defined features. [Maziero et al., 2000]

In the feature-based model, the features can carry information from the process planning, manufacturing and inspection as well. Consequently, the designer can choose the manufacturing processes while he/she is working on the design. This is, in fact, a usage of a Design for Manufacture (DFM) directive, which demands that manufacturing requirements be simultaneously considered with structural and functional requirements in the product design phase. Besides, as the product is being developed, the designer can invoke downstream applications to evaluate the design.

Feature-based design has attracted a lot of attention in CAD/CAM research. [Sillas et al., 2003] In particular, a number of current research projects in CAD/CAM and CIM – Computer Integrated Manufacturing - are working on the integration of CAD/CAPP CAM functions using the feature-based modeling approach.

2.3 FBD+DFM software:

Based on the above DFM principle, an application software has been developed, implemented and tested; it allows for dimensional data drawing upgrades related to the tools of four manufacturing processes that have been chosen to start with. These are: drilling to make a round hole, broaching to make a hole with fine finish internal surface, turning to make o'ring's grooves and milling to make a hole in the most varied ways.

This software is very user friendly as it provides transparency for the user of the necessary modifications to promote the integration of the design with the manufacture, without the need of leaving the CAD environment. It has been developed from the software AUTOCAD® R12 (for Windows) version, which has been a design tool largely used in several industry sectors [Katz, 1993].

The integration between the Feature Based Design window and the corresponding manufacturing process have been implemented through functions written in AUTOLISP, that is the programming language of AUTOCAD®, which allows modifications and customization in AUTOCAD®'s program to assist the users' specific needs.

The Auto LISP language has been developed in such a way which contains the basic commands, data types and capacities of the programming language LISP, as well as additional special functions for operations inside AUTOCAD graphic system. All the necessary customization was made in order to reduce the time spent with repetitive actions.

Through the AUTOLISP programming language it has been developed a link with the EXCELL® software, which is used as database for the cutting tools.

Figure 1 depicts the flow diagram of the software developed herein.

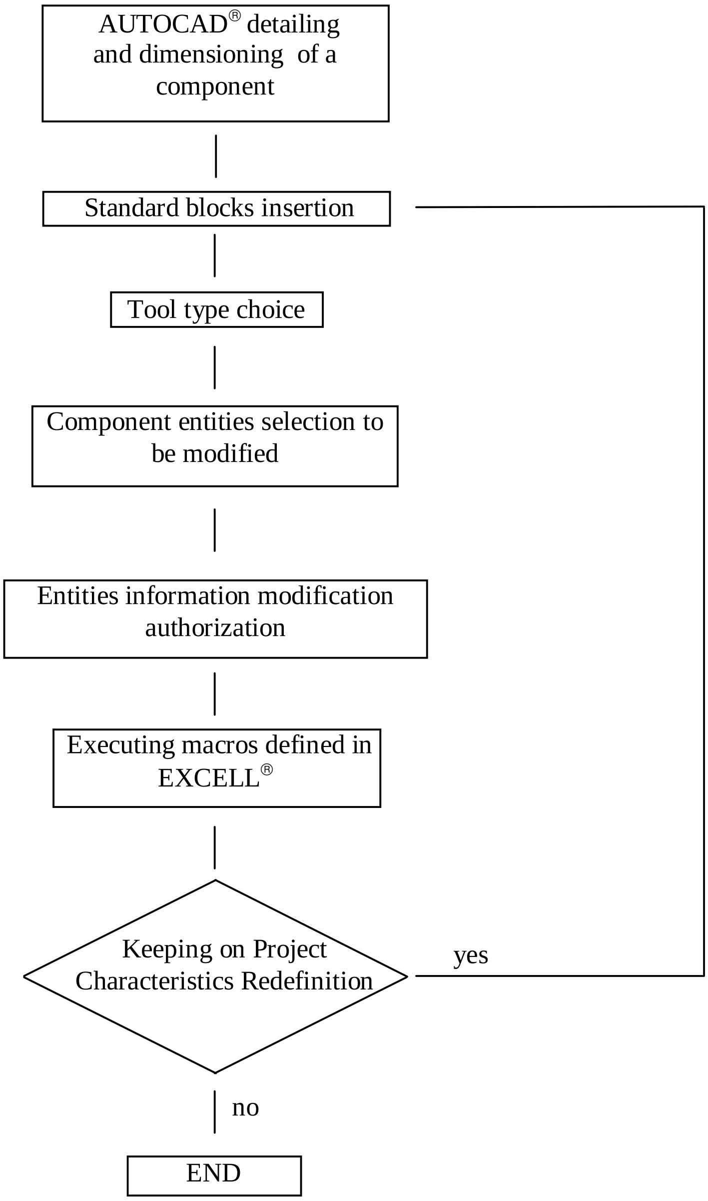

Figure 1: Flow diagram of the FBD – DFM software.

Each of the blocks of Fig. 1 is detailed below.

AUTOCAD® detailing and dimensioning of a component: At this phase, the Product Engineering area elaborates the detailed drawing of a given component, supplied with its details and dimensions as can be shown in Fig. 2. A number of decisions were taken by the designers at this point. A significant number of them does affect the manufacturing stage. It would be desirable for a company, if the designers' decisions in the conceptual phase would match the industrial capacity, avoiding unnecessary modifications in machines, special tools acquisitions, and control equipment able to guarantee the appropriate tolerances of project; among other concerns.

The FBD+DFM software has been developed to guarantee that designers decisions match the industrial capacity, through a quick and updated presentation of the manufacturing tools list, as shown step-by-step through the "o`ring groove's example" depicted in Fig. 2.

Step 1: the designer would start building up the drawing by anyplace up to the position where the o`ring groove's feature will be inserted.

Standard blocks insertion: The objective of this function is to minimize the great variety of FBD+DFM software options. For instance, there are a number of ways for drawing an o'ring channel or a hole of different kinds. It has been decided to create blocks for the drawing of the main features which would, therefore, minimize the mistakes at the drawing phase. The syntax of the blocks is as follow: basic shape, dimensional data and a descriptive text of the channels and holes. The use of these standard blocks is simple and more common each day to AUTOCAD® users, because in many design activities, it is common to create drawings blocks for inserting repetitive details of a component.

Step 2: Once defined the insert position of feature – groove – the designer will use the “Insert” function in AUTOCAD® software to insert the o`ring groove’s feature, as shown in Fig. 3. The following parameters need to be defined:

- Block Name: the name of o`ring groove’s feature means BEDUP – **BED** (o`ring groove build with **cape chisel**) **UP** (in the position **upstairs**);
- Insert Point: in the end of the line or in the intersection of two lines, as shown in Fig. 3;
- Scale Factor X: default;
- Scale Factor Y: default;
- Rotation Angle: default;

Afterwards, the designer will use the “Explode” function in the same software to select and split the entities of the o`ring groove’s feature, to permit its individual and automatic running by the FBD+DFM software.

Tool type choice: A choice of the best cutting tool that meets the project needs is made at this stage. Among all the tools available a set has been chosen to start with. These allow the execution of:

- Channels in a round piece (cape chisel),
- Round holes or holes in the most varied ways, both through holes and blind holes , in the most varied surfaces of the piece (drills and/or mills);
- Round holes, with fine finish internal surface, in the most varied surfaces of the piece (broaches);
- Round holes with two different diameters (drill-guide and/or drills with two diameters), usually used for screw adjustments in that the project doesn't allow the screw heads to be visible;

Step 3: Inside AUTOCAD® software, the designer will find at the menu, the function “Tools”, that shows a set of tools that have been chosen to start with and the system wait the selection of the o`ring groove tool.

Drawing component entities selection to be modified: This phase refers to the selection of several entities of the drawing, as shown in Fig. 4, following a pre-defined sequence, which might be modified by the choice of a specific tool of the previous step.

Step 4: After selecting the o`ring groove tool, the FBD+DFM software will start, automatically, a link between AUTOCAD® software and EXCELL® software, that shows an o`ring groove worksheet.

At the same time, the AUTOCAD® software will wait the selection of all o`ring groove drawing entities.

The sequence of events, as shown in Fig. 4, will be:

- Left vertical line;
- Template radius;
- Central horizontal line;
- Template radius;
- Right vertical line;
- Dimension in front of grooving;
- Dimension in vertical position;
- Dimension of radius;
- Text above;
- Text below.

After selecting all entities selection, AUTOCAD® software will inform the number of parameters exported to EXCELL® software.

Entities information modification authorization: This is the checking and confirmation phase, when a cutting tool is chosen from the database of EXCELL®. The user analyzes the list of tools (separate in electronic spreadsheets for tool type) available in Tooling Warehouse menu and chooses the code of the tool that best meets the needs of the design, as shown in Fig.5.

Step 5: Inside EXCELL® software, the designer will choose the best o`ring groove cutting tool that meets the project needs. Afterwards, he (she) will inform in a specific cell, the code of cutting tool.

Executing macros defined in EXCELL®: This is a step to automatically redefine the component’s drawing entities, as shown in Fig.6, based upon the information of the Tooling Warehouse electronic spreadsheets.

Step 6: Inside EXCELL® software, the designer will find the function "Tools" and then he/she will select in the menu bar the function "Macro" that shows a set of macro procedures related with o`ring groove worksheet, where he/she will choose the macro BEDUP.

At this point, the FBD+DFM software will upgrade automatically the dimensional data drawing related to o`ring groove cutting tool which confirms that designers decisions to match the industrial capacity.

Keeping on Project Characteristics Redefinition: At this point, the user decides either to keep on working in the redefinition of the characteristics of the drawing of another detail or to begin the project of a new component;

END: Closing phase of the design phase.

In order to illustrate the flow diagram above, a practical example of the proposed method is graphically described in Fig. 2 to 7 as follow.

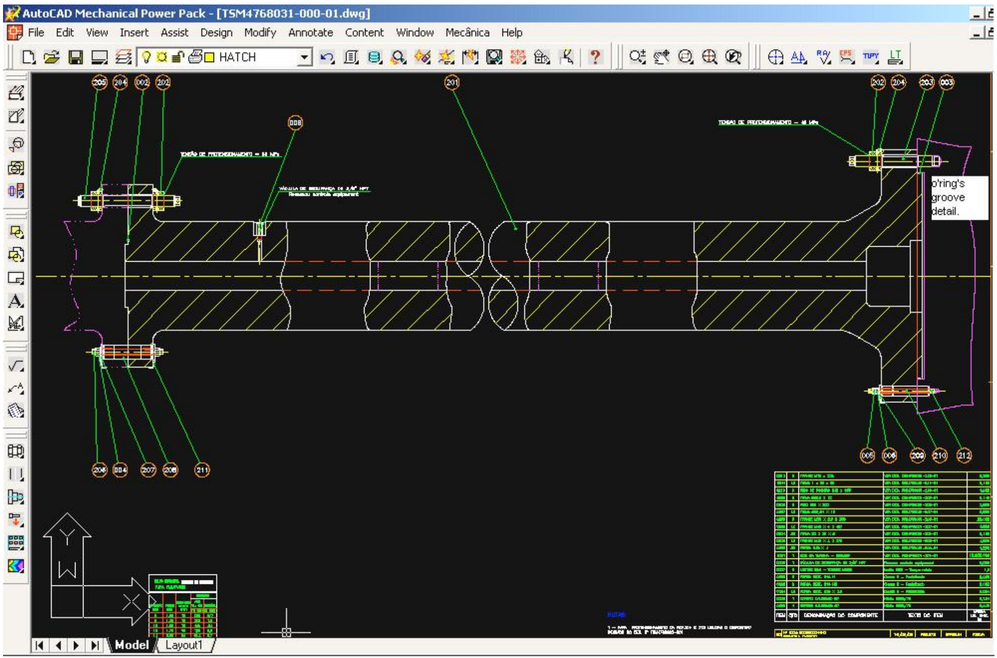

Figure 2: Shaft drawing with details and dimensions.

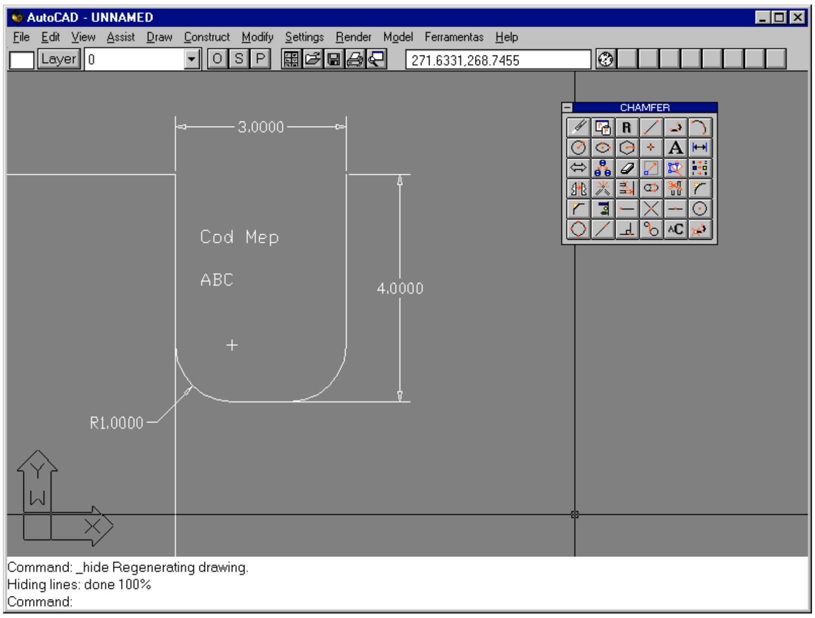

Figure 3: Standard block insertion.

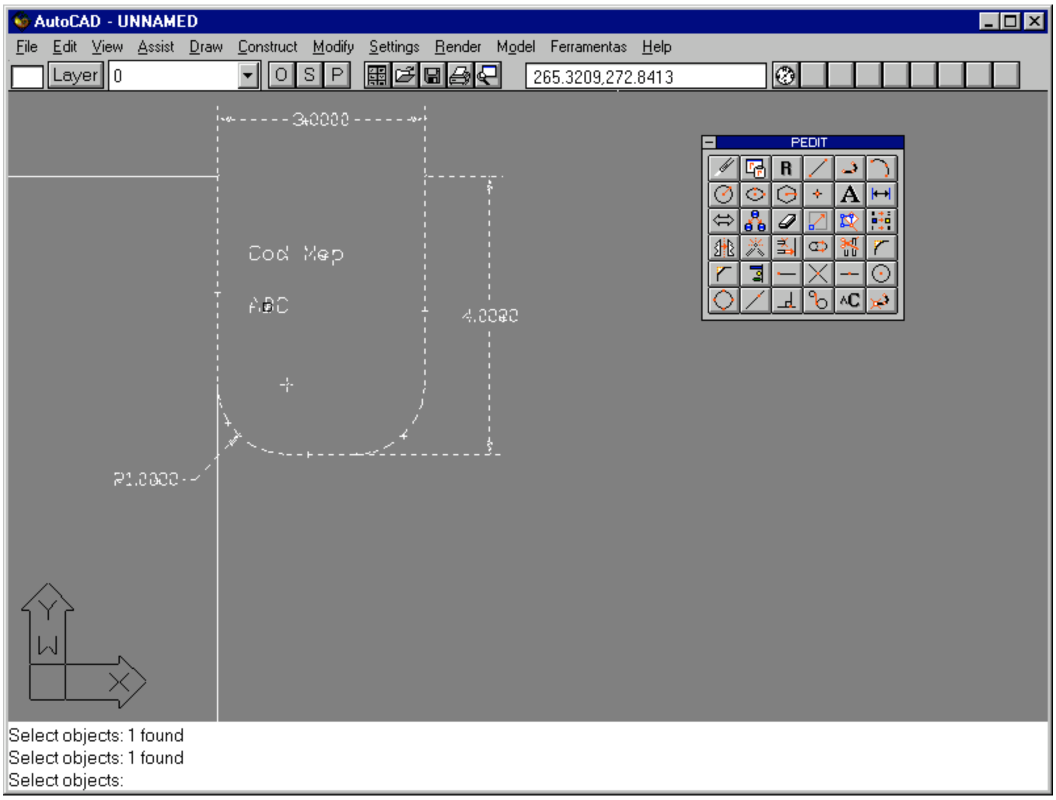

Figure 4: Selection of the entities that will be changed.

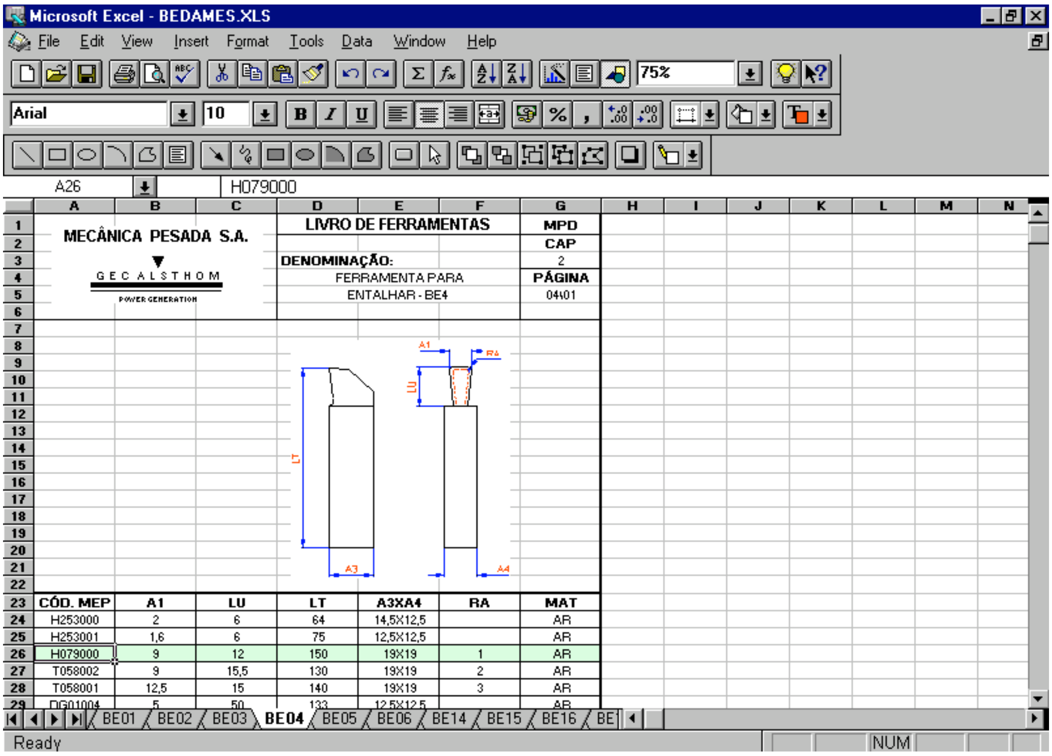

Figure 5: Selection of the cutting tool in the EXCELL®

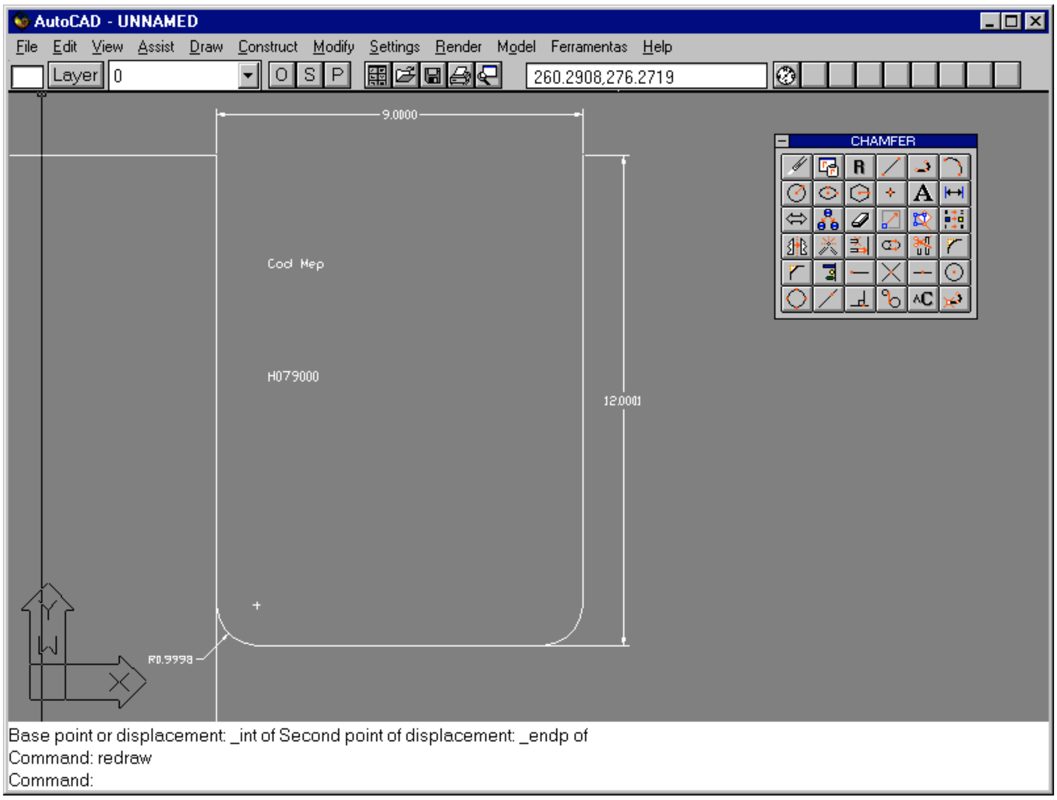

Figure 6: Redefinition of the component’s drawing entities.

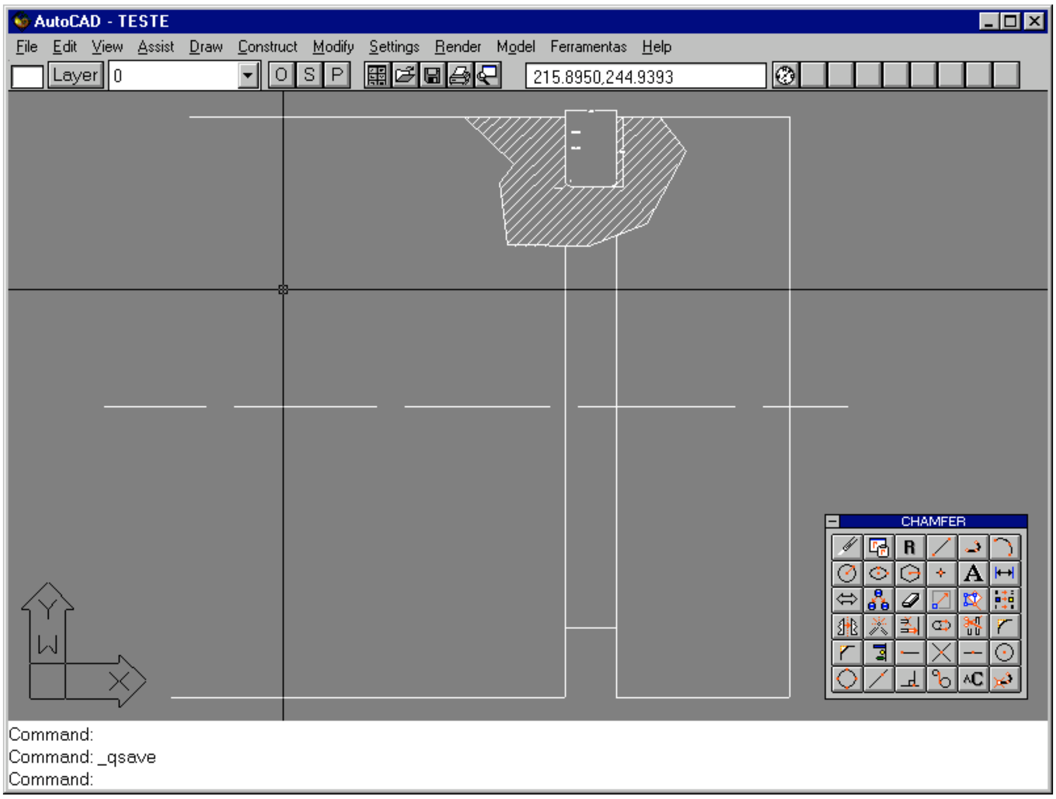

Figure 7: Closing of the component’s detail drawing.

2.3.1. Industrial case study

The FBD+DFM software was used experimentally by a number of engineers and designers of a company which designs and manufactures large and heavy metallic parts for hydroelectric power stations. They were given an instruction manual of the software and were requested to use it in their daily tasks. Then they were requested them to fulfill a questionnaire to evaluate the software performance. Some questions specifically focused on measuring the facility of the method used: all users answered that the software was easy to use. They were also questioned whether the modifications the software suggested them (diameter of the drill, for instance) was seen as a problem for them. They were also unanimous in saying that this did not pose a great problem. In the literature, some authors think that this approach restricts the designers and engineers' creativity

2.3.2. Results:

Besides the qualitative aspects mentioned above, the following results were also observed:

- Reduction of 15% in the design lead time;
- Reduction of 25% in special cutting tool expenses: the engineers tend to use the cutting tools available in the company because the can easily consult the Tool Warehouse database.
- Automatic updating of the component drawings from the new cutting tools technical data;
- Reduction of the review drawing number executed by Engineering Department: it was common the Design Engineering Department to alter the drawings of pieces which was not compatible to the cutting tools dimensions;
- Advanced acquisition of special tools, mainly when supplying tools periods are long, allowing more time to test and to develop special high performance tools, which affect the production directly.

2.3.3. Conclusions:

Taking into account all the qualitative and quantitative earnings mentioned above and the answers obtained from the questionnaire, it is possible to conclude that an important step has been achieved for the integration between design and manufacturing within an industrial environment. This is mainly due to the design-by-features approach used as a background for the development of the application software described herein.

The next steps for further develop the proposed software include the features that would allow other manufacturing processes to be incorporate through the description of their respective tools, such as taps, for screwed holes, taper drills and/or taper mills for taper holes, taper broaches for fine finish internal surface taper holes, center drills for centering holes and shape mills for cutting special grooves.

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