Proceedings of the 17th International Conference on Manufacturing Systems – ICMaS
ISSN 1842-3183
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Bucharest, Romania

IMPLEMENTING DESIGN FOR MANUFACTURE RULES IN POCKET FEATURES

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Abstract: *Design for manufacture (DFM) is the practice of designing products with manufacturing issues in mind into an intelligent system, which translates 3D solid models into manufacturable features. To apply design for manufacture rules (guidelines), they have to be systematized and organized into a hierarchical rule system. Rules at the higher level of the hierarchical system are applied to more generic manufacturing features, and specific rules are applied to more detailed features which enable to minimize the number of rules and repetition. Violation of the design for manufacture rules in the features, their characteristics and manufacturing capabilities are examined in the system. Manufacturability analysis (such as production type, materials, tolerances, surface finish, feature characteristics and accessibility) is also taken into consideration.*

Key words: *design for manufacture (DFM), computer aided design (CAD), design, machining features & manufacturing features.*

1. INTRODUCTION

The principles of design for manufacture (DFM) and its application are not really new. It originates from a person named Eli Whitney who introduced the interchangeable parts concept. The intensive development and progress in DFM have played an important role in producing high performance hardware and software at affordable prices in the computational resources during the last decade but still there is a lot to do in the field of computerization of DFM [1]. In DFM the interaction between designers and engineering's is minimal and manufacturing issues are superficially considered from the beginning of a design. DFM is the tool that enhances a number of general rules about the manufacturability of a part.

The purpose of this research is to develop a hierarchical design for manufacture system for implementation of DFM rules which can help the designers during the design stage with manufacturing constraints information.

2. DEFINITION OF FEATURES

Depending upon the manufacturing process, feature information is considered to be about volumes of material to be removed or to be added. Features represent the engineering meaning or significance of the geometry of a part or assembly. A feature is a set of faces or regions of one part with distinct topological, geometrical and/ or manufacturing information. Features characterize the product and help in analyzing the design concurrently using numerical or knowledge-based system [2]. Different ideas have been presented from different backgrounds. Two of them are:

"A feature is a region of interest on the surface of a part" [3].

"Features are defined as geometric and topological patterns of interest in a part model and which represent high level entities useful in part analysis" [4].

3. DESIGN FEATURES

Features used at the design stage defined by the user or from the CAD modeler library called design feature and which do not take into consideration any manufacturing, assembly or inspection constrains. It is impossible to produce the shape with the available technology. There have three types of design features such as: depression, protrusion, and transition. A boss feature is the depression feature as an increment of the shape.

A pocket feature is the protrusion feature as a decrement of the shape. Depending upon the profile whether it is convex or concave a transition feature could be either a decrement or an increment. Slot, hole, pocket, rounding, cylinder, block, protrusion, cut, chamfer, user defined features, etc are the examples of design features [5, 6 ,7]. Fig. 1a indicates the correct Pocket design and 1b, 1c indicates the incorrect pocket design.

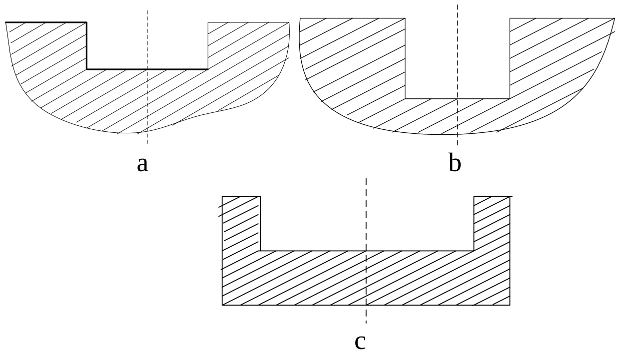

Fig. 1. (a) Pocket feature (b) Impossible geometry (c) Element with low strength.

4. MANUFACTURING FEATURES

A manufacturing feature is typically defined as a collection of related geometric elements which as a whole correspond to a particular manufacturing method or process or can be used to reason about the suitable manufacturing methods or processes for creating the geometry [2]. A manufacturing feature is a feature which is interpreted as a continuous volume that can be removed by a single machining operation in a single set-up [8]. It depends on both the shape and size of the geometric feature and manufacturing processes to be used to produce this feature [9]. We can conclude that a manufacturing feature is the function of machine tools, set-up, tools and parts. Hole, pocket, open pocket, face, boss, step, open step, slot, notch, grove, knurl, thread, fillet, chamfer, etc are the examples of manufacturing features that can be found [10 ,11].

5. DFM PROCEDURE

Martin O' Driscoll [12] in his work Design for Manufacture described the principle of DFM which avoids the redesign and unexpected cost through the integration of the activities indicated in Fig. 1. The proposed DFM procedure contains a descriptive guide concerning the activities which should be undertaken to improve the manufacturability of a product.

6. FEATURE RECOGNITION METHOD

In this paper Graph-based recognition method has been used for recognizing manufacturing features. The example below in Fig. 3, a solid rectangular work piece is considered to be machined. The interpretation and mapping of the design features into machining feature is done using graph-based methods by identifying the removal volumes from the initial work piece and attribute them to manufacturing features. Joshi and Chang [13] in their work developed the method which is a good example of a graph-based approach to feature recognition. The features that the system can locate are described by a series of feature rules. The rules are built up in an ad-hoc way so that at times features that have slight variations from the normal case may not be located. In 1982 kyprianou [15] in his work first implement this system and examples of other systems developed using this method are by Van Houten [14] and Van't Erve [16]. Then in 1987 Falcidieno [17] suggested that the faces of the model do not necessarily imply any information about the extent of material to be removed or added in order to create a feature. Faces, edges and vertices which are boundary information are used to close the boundary of a feature. These new faces are then incorporated into the face adjacency graph and recognition is then carried out by looking for cut vertices in this face adjacency graph.

7. POCKET FEATURES

Figs. 4a and 4b is the example of different pocket features which is extracted by the feature recognition method.

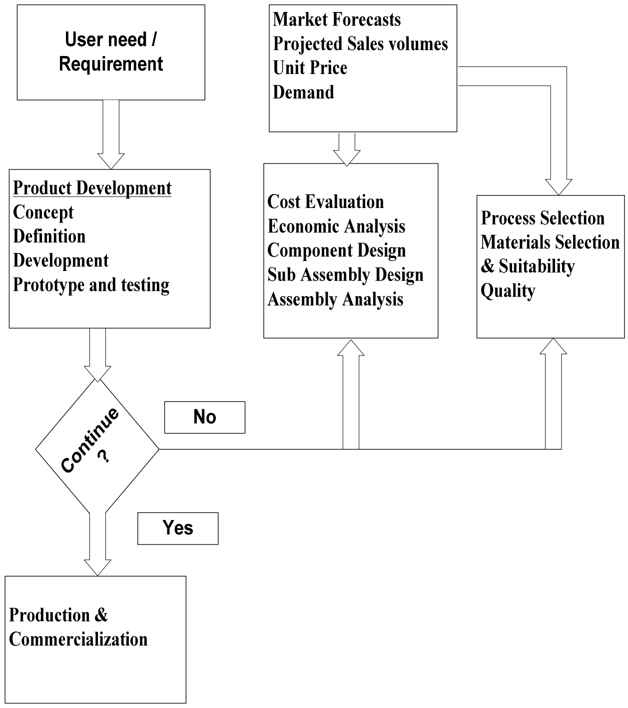

Fig. 2. Typical DFM flow chart.

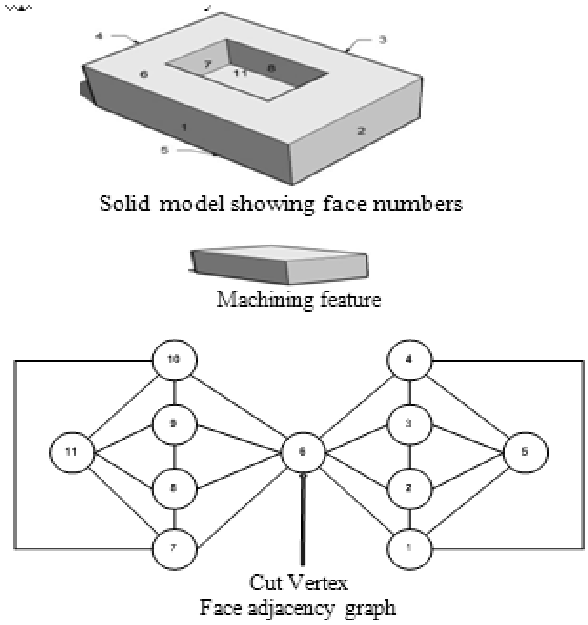

Fig. 3. Graph-based approach.

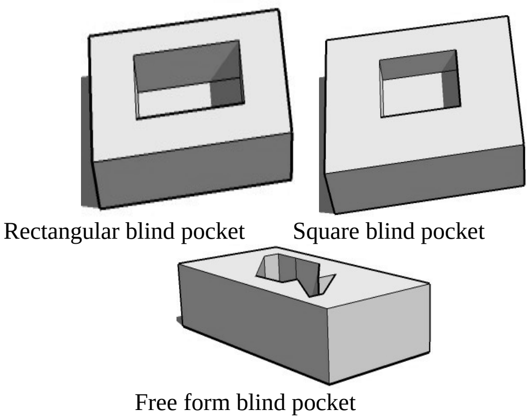

Fig. 4a. Blind pocket features.

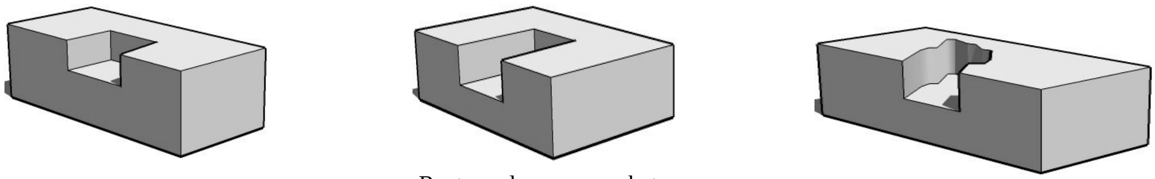

Fig. 4b. Open pocket features.

8. FEATURE CLASSIFICATION

A new approach of DFM rules is presented in this paper. Depending upon the manufacturing processes pocket feature can be classified into two types such as Material Removal and Material Transformation. Material Removal means how much material can be removed by machining processes and Material Transformation means by which processes material can be transform to produce the proper shape. Then pocket features have been classified into three main categories such as Machined pockets, Cast pockets and Formed pockets. After that every main category has been classified into two sub-categories, open pocket and blind pocket. Every sub-category contains different pocket features with their manufacturing processes. Figs. 5a and 5b show the classification of Machined pocket features based on the examples as indicated in Fig. 4.

In Fig. 5a and 5b only machined pocket classification have been shown elaborately. Another two categories such as formed pockets and cast pockets which are the part of material transformation, is possible to classify the same way as machined pocket. However in the open pocket classification of machined pockets; Rectangular pocket with rounded end, Square pocket with rounded end and Free form pocket have been shown with their possible manufacturing processes.

On the other hand blind pockets can be classified into three categories with their possible manufacturing processes such as Rectangular pocket with rounded end, Square pocket with rounded end, Free form pocket. From those classifications the Rectangular pocket feature has been describe elaborately.

Nevertheless the design information knowledge bases such as design process, factory representation and product representation are queried to enable the early part of the design process to be complete, and then the manufacturing information section together with data from the design information section which are used to provide for any downstream manufacturing considerations, are also queried.

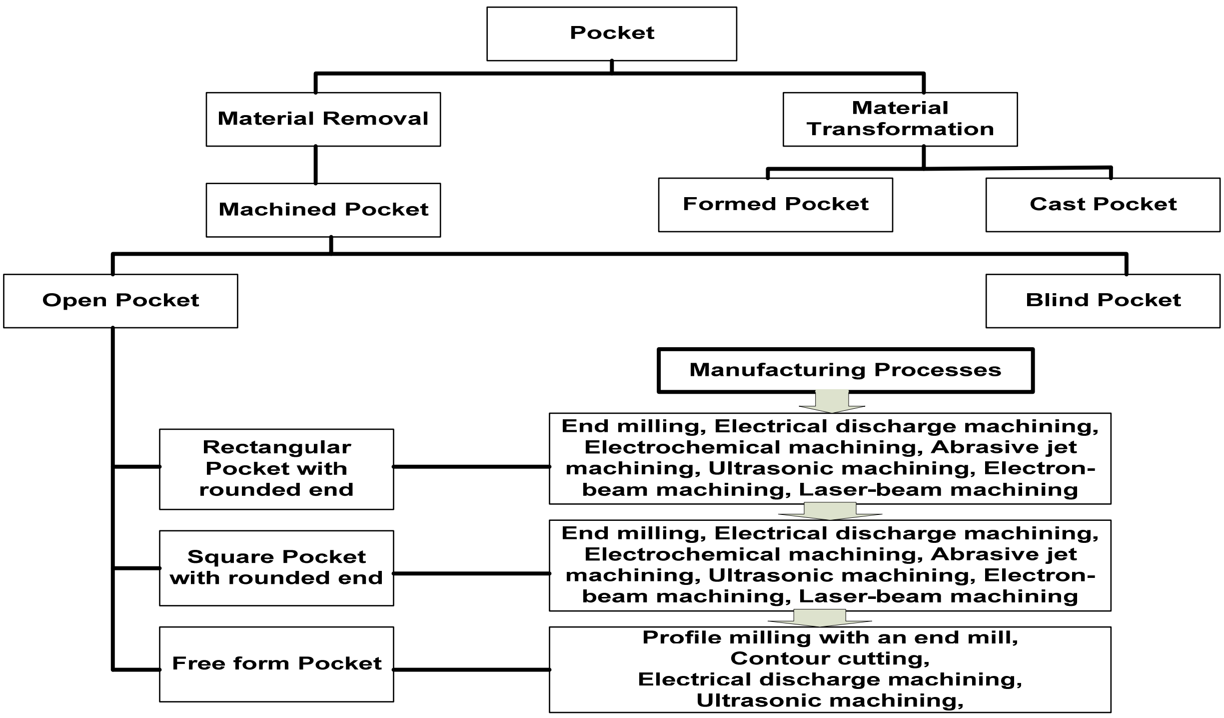

Fig. 5a. Open pocket classification of machined pocket.

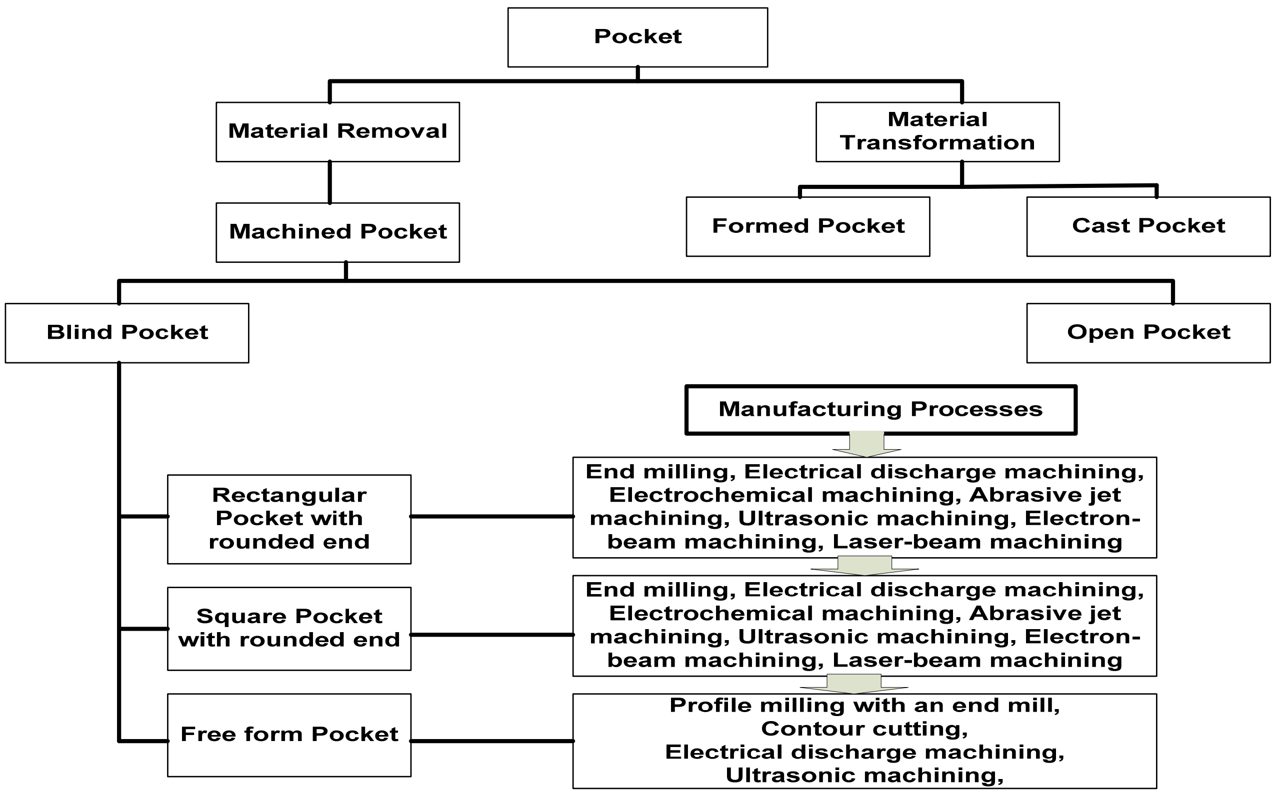

Fig. 5b. Blind pocket classification of machined pocket.

9. GENERAL DESIGN GUIDELINES

The general design guidelines for pocket features, applied to generic features such as Machined pockets, Formed pockets and Cast pockets which have been classified in Figs. 5a and 5b.

Create a design with lower number of parts where possible by designing a part so that it performs several functions. As the number of parts goes up, the total cost of fabricating and assembling the product goes up.

Additionally creating design documents and manufacturing processes are additive, resulting in a more expensive product due to NRE (Non-Recurring Engineering) and manufacturing costs.

Avoid machining operation if possible. For higher volume parts, consider castings, extrusions or other volume manufacturing processes to reduce machining and in-machining time.

Avoid design for high labor-cost operations whenever possible. As an example, a punch-press-pierced hole can be made more quickly than a hole can be drilled. Drilling in turn is quicker than boring. Tumble deburing requires less labor than hand deburing. To avoid costly secondary operations like grinding, reaming, lapping etc, specify the most liberal surface finish and dimensional tolerances whenever possible consistent with the function of the surface.

Generally design a part in such a way that as many operation as possible can be performed without other machining operation. This reduces the number of operations and handling time but equally importantly promotes accuracy since the needed precision can be built into the tooling and equipment. Select high machinability materials as much as possible. Hardened materials are difficult to machine. Harder materials decrease the cutting tool life.

The design should be in such a way that it can be easily fixtured and secure holding is ensured during machining operations. To assure a secure set-up large mounting surfaces with parallel clamping surfaces should be provided.

Avoid the design of parts that require sharp corners and sharp points in cutting tools because these increase the probability of cutting tool breakage. Use generous fillets and radii. Generally rounded corners provide a number of advantages. There is less stress concentration on the part and on the tool. Some exceptions:

"The external corners of a powder-metal part where surfaces formed by the punch face intersect surfaces formed by the die walls, will be sharp".

Design parts to be rigid enough to withstand clamping forces without distortion. Thin, slender work pieces are difficult to support properly to withstand clamping and cutting forces. The cutter tool exerts several forces against the workpiece which causes vibration and chatter, so that the clamping forces are necessary to hold the workpiece securely.

Avoid generalized statements on drawing which may be difficult for manufacturing personnel to interpret.

Examples for incorrect statements are: "Polish this surface", "Corners must be sharp", "Tool marks are not permitted" and "Assemblies must exhibit good workmanship".

Avoid the design of special tooling operations (dies, form cutter, gun drilling etc) whenever possible. Except for the highest levels of production, where the labor and materials saving of special tooling enable their costs to be amortized.

Designers should become familiar with general purpose and standard tooling.

Avoid dimensioning from the space points but from the specific surfaces or points on the part itself as much as possible. Its greatly facilitates fixture and gauge making and helps avoid tooling, gauge, and measurement errors.

10. MANUFACTURABILITY ANALYSIS

As can be seen in Table 1, a Rectangular through Slot is shown to have characteristics which are Cutter diameters, Pocket depth, and Pocket width. The geometrical and topological characteristics are known from the design stage. The DFM system provides the information about the production type, Material, Tolerances and the surface finish of the part for utilization of the designer. In our example the End Milling process is selected with the constrains of this process applied to the Pocket feature and warn the designer about the limitation of the process.

11. DESIGN CONSTRAINS OF END MILLING

Design parts in such a way that includes corner shapes, chamfers, depth, width, radii and overall forms which are available in standard cutters. Special cutters are costly and difficult to maintain.

To avoid difficulty of milling cutters (have a finite radius), designs with internal cavities and pockets with sharp corners should be avoided.

Avoid a design that specifies a blended radius because exact blending is difficult to achieve.

Concave surfaces without fillets between them can not be milled, due to the tool radius. Unmachined areas remain (Fig. 6). Design parts with standard keyway dimensions which permits standard cutter to travel parallel to the center axis of the shaft and can produce both sides and ends in one operation from its own radius.

Design parts with small steps or radii or inclined flange or shoulder surfaces for the clearance of cutter path when requires the milling of surfaces adjacent to a shoulder or flange. In order to increase the cutter life design should not include milling at parting lines, flash areas and weldments. Designs should be in considerations that the clearance for the milling cutter is important. Design parts that do not allow large surfaces to be machined. Design parts that include fewest separate operations which is more economical.

Avoid deep pockets with small fillet radius between the surfaces (Fig. 7).

Table 1

Manufacturability Analysis

Feature	Rectangular blind pocket
Production type	Mass production
Material	Steel
Surface finish [µm]	1.5-3.8 µm
Depth of the pocket [mm]	20 mm
Width of the pocket [mm]	6.3-25 mm
Tolerances [mm]	±0.05- ±0.06 mm
Manufacturing process	End milling

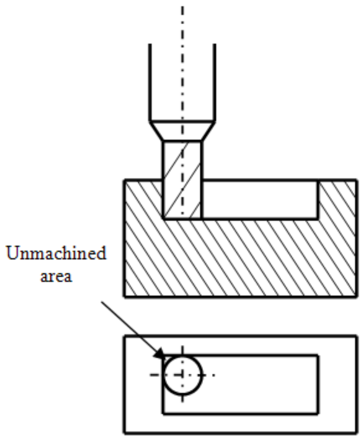

Fig. 6. Concave surface without fillets.

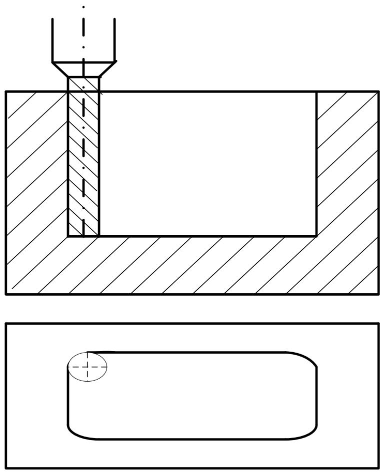

Fig. 7. Deep pocket with small fillet radius.

12. CONCLUSIONS

The performance of production processes suffered poorly in the manufacturing sector due to insufficient reconciliation of process capabilities with design requirements. Special processes are often poorly understood and frequently modified during the production time. In order to avoid the practice of "do it anyway" instead of "do it right" for set up plan requirements, design for manufacture (DFM) is used. Due to complexity of detail design and processing, it is still impossible to completely replace the human decision factor with an automatic manufacturing analysis system. Poor designs increase the product cost. Product cost includes the design costs and the manufacturing costs. However Labor cost (direct and indirect) 2-15% of total, Materials and manufacturing processes 50-80% of total and Overheads 15-45% of total are the manufacturing costs. Implementation of DFM in an organization is heavily dependent on the effectiveness of its Product Design Process (PDP).

This approach can be added to design and manufacturing tool by which a designer and manufacturer will be aware of those design constrains.

Each manufacturing process contains design recommendations from that a designer can easily get idea which processes are suitable for which feature for manufacture and is easier to design any product. It is to be mentioned that the DFM system will not restrict the design process, but will give practical information about the manufacturing constrains which may occur during the product manufacture.

The designer can also chose whatever materials manufacturer wants for manufacturing the parts. At the end the user would be aware of the producibility of the product with regard to the choice of material, production type and feature's characteristics.

Acknowledgements

Dublin City University is a partner of the EU-funded FP6 Innovative Production Machines and Systems (I*PROMS) Network of Excellence (www.iproms.org).

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