



Manufacturing complexity evaluation at the design stage for both machining and layered manufacturing

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ABSTRACT

In this paper, a methodology to estimate manufacturing complexity for both machining and layered manufacturing is proposed in order to realize tools (dies or molds) by a combination of a subtractive and an additive process. Manufacturability indexes are calculated at the tool design stage, these indexes provide an accurate view of which areas of the tool will advantageously be machined or manufactured by an additive process. In this case, tools are not seen as single pieces but as 3D puzzles with modules, manufactured aside by the best process and further assembled.

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1. Introduction

1.1. Context of the study

In order to stay competitive, manufacturers have to develop new products in a very short time and with reduced costs, whereas customers require more and more quality and flexibility. These objectives imply two design and manufacturing constraints: a rapid manufacturing and a high level of reactivity when design evolutions are required. The field of tooling (dies and molds) does not break these constraints and one possibility to improve competitiveness is to design and manufacture tools with modular and hybrid points of views.

1.2. Modular point of view

Instead of a one-piece tool, it is seen as a 3D puzzle with modules realized separately and further assembled. The two advantages are: every module may be produced simultaneously and few modules may be changed without changing the whole tool. As it can be seen in the example in Fig. 1, the two alternatives of the product may be advantageously manufactured with the same mold, changing one module corresponding to the product model.

1.3. Hybrid point of view

In the hybrid point of view, tools are decomposed into modules which will be manufactured by the best process, in term of time, cost

and quality. The aim of this approach is to choose the best manufacturing process for each area of the tool. Presently, focus is put on comparison between a subtractive process (high-speed machining) and an additive process (selective laser sintering). Nowadays, a number of additive fabrication technologies are used to produce metal parts and tools. These technologies provide an interesting alternative to CNC machining, especially in quickly manufacturing complex shapes, like conformal cooling channel or difficult-to-machine parts (which previously needed to be manufacture by EDM).

1.4. Hybrid modular tooling

The two points of view, hybrid and modular, have allowed creating rapid tools and rapid prototypes with the Multi-Component Prototype concept [1]. This concept aims to decompose a mechanical prototype part on an assembly of several components. There are two main reasons for the multi-component decomposition:

- To include the evolutionary requirement of the future parts to produce.
- To help designers to choose the best manufacturing process for each component, taking into account time, cost and feasibility of different fabrication technologies.

This paper is focused on the second point. The major problem is how to obtain a well-detailed view of the tool manufacturing complexity at the design stage in order to create a hybrid modular tool with a reduced complexity (and consequently with a lower manufacturing cost). This consideration forces the development of a manufacturability analysis with a well-detailed point of view. Manufacturability must be evaluated for the whole tool to

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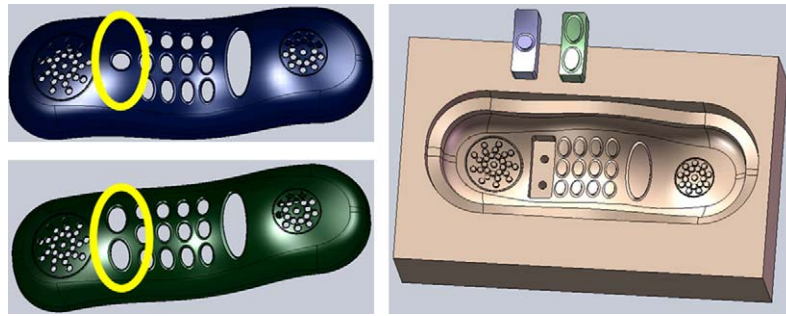


Fig. 1. Example of a modular die for two alternatives of a product.

discriminate which areas are the most complex-to-realize. This manufacturing complexity analysis is the main point of the tool design and manufacturing methodology presented in the next section.

2. Hybrid modular tool design method

The aim of this new methodology is to propose a decomposition of the tool which facilitates its manufacturing. So two points have to be taken into account: the evaluation of the manufacturability of the tool, and a hybrid modular decomposition that can improve the manufacturability. This method is divided into 6 stages, a schematic view is proposed in Fig. 2.

The starting point of this methodology is the one-piece tool CAD model. The manufacturing complexity of this one-piece tool is evaluated with the help of the manufacturability indexes calculation, defined in the next section. Then the modular and hybrid points of view are taken into account in order to create a hybrid modular tool. The manufacturability analysis is performed on this new tool CAD model. The last stage is a comparison between the two manufacturability analyses to quantify the advantages of the hybrid modular design.

This methodology has been implemented on a CAD software (SolidWorks 2007) with Visual Basic language [2].

Section 3 presents the manufacturability analysis for both machining and layered manufacturing.

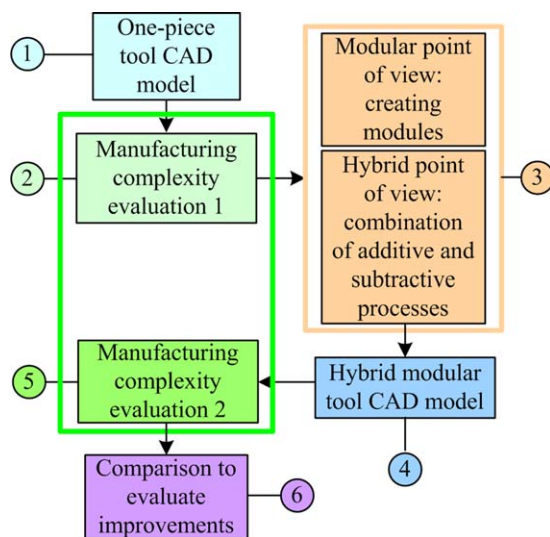


Fig. 2. Hybrid modular tool design methodology.

3. Manufacturing complexity evaluation

3.1. Related works

Many works have been done on manufacturability analysis, especially in the late 1990s, with the Design For Manufacturing (DFM) approach. DFM involves simultaneously considering design goals and manufacturing constraints in order to identify and to alleviate manufacturing problems while the product is being designed; thereby reducing the lead time for product development and improving product quality [3]. Most of the studies on DFM methods imply using a feature decomposition of the part CAD model, and associating manufacturability evaluation with each feature. The major problem is that features usually rely on one specific field. As an example, machining features are developed for CNC machining [4], but manufacturing features for additive technologies are still under development [5]. Furthermore, for free-form surface, usually used in tooling design, features do not bring enough information on the shape. So the hybrid modular tool manufacturability analysis cannot be based on feature decomposition, another tool CAD model decomposition method has to be found.

Each solid modeling method (CSG, B-rep, etc.) has its advantages and disadvantages relative to the others in term of accuracy, robustness, data structure and computing time. The key points are on the representation of parts with irregular surfaces, and approximation of curved surface.

Because there are often few geometric details of the tool that can change the manufacturing process choice (a small curvature radius of a concave shape for example); no information should be lost in the tool CAD model decomposition. And the decomposition accuracy must be at a high level for the areas that are geometrically complex (with lots of changes in surface orientations), whereas it may be lower for quite simple areas (a plane for instance). So octree decomposition [6] seems to be a good candidate for the tool CAD model decomposition.

3.2. Octree concept

An octree is a tree data structure, which represents a three-dimensional object by the division of space into small cubic cells or small parallelepipeds. The size of each cell depends on the local geometric complexity of the object represented [7]. Each cell in space corresponds to a node in the tree and each node is referred to as an octant. To construct an octree, the object is first enclosed by the smallest box that can completely contain the object in any direction. This box (a cube or a parallelepiped) makes up the root level of the octree. It is then subdivided into 8 sub-octants which then represent the first level. The octants are classified into three categories: black (full), white (empty) and grey (partially filled).

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