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Pascal MOGNOL, Jean-Yves HASCOET, Mickaël RIVETTE - Method to obtain hybrid rapid tools with elementary component assembly - Rapid Prototyping Journal - Vol. 19, n°2, p.77-87 - 2013

Purpose – To propose a method to obtain hybrid rapid tools with elementary component assembly.

Design/methodology/approach – Our method, proposes a functional representational model, starting with the product features, analyzed from three points of view:

- a feasibility analysis,

- a manufacturing analysis,

- an assembly and synthesis analysis.

This method, based on CAD Step AP-224 data, must make it possible to obtain an exhaustive list of solutions for the module. The work is illustrated with an industrial example. To construct the Assembly Identity Card (AIC) and test the various parameters that influence the quality of the injected parts, we have produced a hybrid injection mold. The methodology associated with the use of this AIC uses a "representation graph", which makes it possible to propose a set of valid solutions for the assembling the various tooling modules

This method is validated by industrial example.

Findings – The product part is decomposed into a multi-component prototype (MCP), instead of being made as a single part, which optimizes the manufacturing process and enables greater reactivity during the development of the product.

Research limitations/implications – The final goal is to propose a software assistant used in association with CAD system during the design of hybrid rapid tooling. An important work concerning the features recognition must be implemented. The assembly of the different parts of the hybrid rapid tooling must be considered and optimized.

Practical implications – This method allows the selection of the best process technologies form manufacturing tools.

Originality/value – The analysis of manufacturing hybrid rapid tooling has not been studied yet.

Kezwords – Hybrid rapid tooling, Multi component prototype, Hybrid manufacturing, STEP.

1 Introduction

1.1 Context

Today, there are many ways to improve efficiency in manufacturing. However, the traditional cornerstones, which are cost, quality, and time-to-market, are the prime business targets, and mass customization is one of the ways to meet them. It allows a product to be tailored for individual clients while at the same time using the principles of mass production. For many products, the competitive edge of the producer is dependent not only on the price, but also on the choices or variations provided in each product line. Examples of such products range from automobiles (as evidenced by the increasing number of options available for any base model) to electronic products, such as computers. The challenge is to create a variety of products from a common family without a significant tradeoff in production costs or lead time.

In order to address the high cost of this practice, manufacturers develop product families from a common platform that is shared by all the products, the variants of which are designed to fulfil different customer demands. Those variants are created by adding specific components to the basic platform. A small batch with a particular option or set of options is being produced increasingly frequently.

At the same time, products have become more complex, and the time required to develop them is increasingly long and laborious. To counter these trends, the hybrid rapid prototype is beginning to emerge. In this work, rapid tooling and the prototype part are studied.

Tools can be of evolutionary, for bridge tooling or for small series, and parts can be aspects geometrical, functional, or technological prototypes [1, 2].

1.2 Related work

Hybrid rapid prototyping has been presented in some recent papers [3, 4], this research based on the study of two processes: CNC (Computer Numerical Control) and Rapid Prototyping (RP). CNC is used when the quality of the part is greater than what is possible using RP. Their methodology uses STEP AP-203 data, but without taking into account the ISO specifications of the model. Likewise, a methodology was developed for part manufacture that would allow the decomposition of a part into a space partitioning [5]. The weakness of these studies is that only build accessibility is considered, and no choice of an adequate process is proposed.

Moreover, assembly of the hybrid prototypes, and its design repercussions, were never taken into account, nor was the interaction between manufacture, assembly, and design examined.

Some research on product families [6, 7] and design for assembly [8] related only to the assembly of subset of a product (a power supply, for example), and does not address the assembly of cast solid products composed of hybrid elements (injection tooling, for example).

Our concept, by contrast, is aimed at decomposing a part into a Multi Component Prototype (MCP), instead of considering it as made in one piece. The two main reasons for this are to include the evolutionary requirement of the prototype with regard to the tests that are performed on it, and to optimize the manufacturing process locally, with regard to the component's geometry and functional requirements. As a result, only one component, or a small number of them, would have to be remanufactured individually, in order to update the prototype geometry for testing purposes.

A methodology for the assembly of the multi-component part by extracting and using entities of the CAD model is also proposed.

A new part decomposition for a prototype in order to guarantee the functionality requirements and to allow the evolutionary of its geometry was proposed. Furthermore each component of the new, partitioned part is built using the most appropriate process. The assembly of components is design to have the same tested characteristic as the "single piece" part. This new approach is entitled "hybrid evolutionary prototypes". Our various analyses are based on CAD STEP specifications, and, more particularly, on Application Protocol (AP)-224.

2 MCP concept (Multi-Component Prototype)

2.1 Presentation

The objective of the MCP concept, which is presented in Figure 1, is to allow the evolution of parts for testing purposes. The methodology has been developed based on feature analysis, but, unlike research performed in CAPP [10], without using automatic feature recognition [9]. In our case, we used Step-AP224 entities in the CAD model of the part, because it is essential to have certain information available, along with the geometry, like tolerances and part properties. At this time there is no commercial software to extract automatically this step-AP22e entities. We use automatic extraction software developed by the laboratory National Research Laboratory [11] for STEP-NC Technology. This software is called PosSFP. Subsequently, a 3D partitioning of the part is performed in Functional Components (FC) (Figure 1).

The result is the definition of all the components that make up the Multi-Component Prototype [12], which is like a 3D puzzle of the part. The individual components are then manufactured, using various selected processes and materials [10], followed by assembly of all the components for experimental testing. If the results of the tests do not match the technical requirements, then only a certain number of components have to be redesigned and remanufactured in order to update the prototype. The use of the MCP concept to redesign and remanufacture the prototypes makes it possible to reduce the costs incurred and the time spent for each iteration in the loop. When the test results match the functional requirements, the design is validated.

Figure 1: Multi-Component Prototype

2.2 STEP: Input data

The Standard for the Exchange of Product model data (STEP ISO 10303) provides a neutral computer-interpretable representation of product data throughout the life cycle of a product, independent of any particular system.

STEP is organized as a series of chapters, each published separately. These chapters fall into one of the following series: method description, integrated resources, application protocols, abstract test suites, implementation methods, and conformance testing. STEP uses application protocols (APs) to specify the representation of product information for one or more applications. It is expected that several hundred APs may be developed to support the many industrial applications. STEP AP-203 is usually used for exchanging neutral format data between CAD systems. STEP AP-224 is a manufacturing feature-oriented description. In our study, we use STEP AP-224 (Figure 2).

Figure 2. STEP AP-224 standard

This chapter of ISO 10303 specifies the information needed to define the product data required to manufacture a mechanical part. These data are based on existing designs of the part, the shapes of which are represented by machining features.

Chapter AP224 contains all the information and capabilities needed to manufacture the required part (Figure 2):

- All the necessary CAD geometry and topology in a neutral format

- Machining feature information, such as hole, boss, slot, groove, pocket, chamfer, and fillet (there are 20 manufacturing features)

- Dimensional and geometric tolerance information

- Part properties, such as material properties, process properties, and material hardness

- Administrative information, such as approval, part name and ID, delivery date, and quantity

- The capability to handle both discrete parts and assemblies of parts

3 Method

The MCP concept involves realizing a product from a single-piece part. For experimental testing, an MCP must have the same functionality as the single-piece prototype from which it comes. Otherwise, results cannot be interpreted, as would be the case for a single-piece part. Therefore, all the activities shown in Figure 3 have to be perfectly analyzed to obtain a Hybrid Rapid Tooling with the same characteristics as its cast solid model.

Each analysis has its own knowledge. The feasibility analysis synthesizes the previous analysis to propose an MCP in conformity with initial requirements.

A previous paper [13] described the feasibility analysis, the goal of which is to group together entities that participate in the same functions in the same piece of the puzzle. The manufacturing analysis [14] proposes the best manufacturing process for each component of the MCP studied. Below, we develop the assembly and synthesis analysis.

Figure 3: MCP concept

The assembly and synthesis analysis allows the various modules to be assembled in accordance with the functional and technological specifications.

For this analysis, standard assemblies called AICs (Assembly Identity Cards) have been created. The TLIC method [15] is used to calculate adjustments to each assembly. In addition, the analysis combines the results obtained previously and provides a coherent set of assembled modules, made with the selected process and meeting the original specifications.

We present this analysis to describe the various steps of the method using the industrial injection mold as an example (Figure 4), in this case the rear door seal of a vehicle. The objective is to develop a tool to manufacture several variants of the seal, and to optimize the shape of some parts of the mold in terms of process.

Figure 4: Automotive seal

This prototype mold is used during product and manufacturing process development.

The method represents the tools in graphical form, using a “representation graph”. The data required to construct this graph are based on the manufacturing and feasibility analysis. These data are interpreted using the fuzzy logic technique, which was developed on the SPARK Viewer software, version 2.502.

The test results and manufacturing feasibility are presented next [12, 16]. The speech focuses on the assembly and synthesis analysis.

3.1 Entity extraction

The starting point is the Ap-224 entities of the CAD model. The STEP-trans software used for obtaining these entities from the CAD model automatically gives the list of the Ap-224 features on a simple part. Then, the feasibility, evolutionary, and functionality aspects are identified. With this analysis, these elementary entities are grouped into an Elementary Functional Component, called an EFC. A schema is proposed to represent the CAD model, in which the AP-224 entities are represented by a node, the topologic link by an arc, and the EFC by a group of nodes. The links between EFCs are called ICC. Concurrently, during the manufacturing analysis, the processes best adapted for manufacturing each entity are revealed. This analysis is based on the information contained in the AP-224 feature geometry, and in the dimensional and geometric tolerance information (Figure 5 and Figure 6).

Figure 5: AP-224 entities

Figure 6: AP-224 entities

In this example, the stripping constraints call for five mold parting surfaces, which are the five independent parts noted “mold parting surfaces Zi” considered to make up the equipment (Figure 7).

Figure 7: Mold parting surfaces

3.2 Feasibility analysis

The feasibility analysis addresses the functional criteria (ISO specifications), the evolutionary criteria, and the topological configuration of the AP-224 entities making up the part. The goal is to group together features that participate in the same functions in the same piece of the puzzle. It is considered that features that are highly positioned from a qualitative point of view, or which have a particular topological configuration, must be in the same FC.

There are three types of topological relationships: Inclusion, Intersection or Contact.

A feature F2 is included in another feature F1 if the volume of F2 is completely contained in the volume of F1. A feature F1 is related to an intersection with feature F2 if these two features are at least two surfaces of intersection A feature F1 is in contact with a feature F2 if there is exactly one common surface.

This topological information is extracted manually from AP-224 entities. 2 entities that are included or in intersection can not be separated.

Our methodology takes into account the evolutionary criteria. For the moment, this property is represented by a Boolean variable call “Evol”. Its value is “true” when one or many of the surfaces included in the feature must be updated.

In the example, the feasibility analysis gives the list of AP-224 entities and their properties, as well as the list and details of the links between AP-224 entities (see Figure 8).

Here, for example (Figure 8), there is a link, L2, between entity C and entity A. This is an inclusion-type link, which means that entity C includes entity A, i.e. the volume of entity C is completely contained in the volume of entity A). Thus the entities A and B can not be separated.

Figure 8: Entity links

We obtain the EFC as follows:

[C,A]; [FZ4, GZ4, UZ4]; [FZ1, GZ1, UZ1]; [FZ1, LZ1]

3.3 Manufacturing analysis

During the manufacturing analysis, each AP-224 entity is analyzed to define the best fabrication processes for manufacturing them. For each process studied, every entity is marked (given a score of 1 to 10), 0 if the process is not available to 10 if the process is perfectly adapted to manufacturing the entity. [16] To obtain these marks, four processors are used. The cost processor estimates the manufacturing cost of each feature, without considering “fixed costs”. The time processor estimates the manufacturing time for each feature, without considering non productive time.

For HSM, the manufacturing time and cost indexes of a feature are estimated from the removal volume of this feature, taken from STEP-AP224 as Removal_volume.

For EDM, they are estimated by an evaluation of the time and cost which are necessary for realizing the electrode and the spark.

And for DMLS, they are estimated by the calculation of the manufacturing time and cost of the smallest parallelepiped which contains the whole feature.

After this first estimation, the manufacturing time and cost indexes are modified by a feasibility factor ϕ. This factor represents the manufacturing difficulty of the feature. It depends on the manufacturing process and some qualitative and dimensional parameters of the feature. It varies from 0 (low level of feasibility) to 1 (high level of feasibility). In fact, the manufacturing time and cost evaluation is accomplished on a volume analysis, and it does not take into account realization difficulties, like a small radius, a small fabrication tolerance interval…

At the end of the analysis, fixed costs and non productive times are taken into account by the classification processor. This processor gives all the modules (features gathered together) and their assigned processes, as well as the global estimated manufacturing time and cost.

Here, for example (Figure 9), the EDM Process has been selected to manufacture the entity N. Now, the DMLS process could be used, but the HSM process is completely unsuitable..

Figure 9: Marks

3.4 Assembly and synthesis analysis

The assembly and synthesis analysis consists of two parts: the creation of the representation graph and its treatment by the fabrication and assembly approach. A synthesis is then performed in order to propose a final solution (Erreur : source de la référence non trouvée). The extraction of entities AP-224 is manual. The extraction data for the feasibility analysis and manufacturing analysis is manual. Processing of these data using simple rules and is easily automated. The last step, assembly analysis and synthesis use a graph of representation. The rules used are easy to automate.

3.4.1 Representation graph

The representation graph describes the relationships between the entities based on the rules of construction for the feasibility analysis. Entities are represented by squares, and the connections between them by lines. The formalism used, described in Figure 11, gives the results obtained in Figure 8.

Figure 10: Graph

Figure 11: Captions

3.4.2 Treatment of the representation graph

The graph is resolved with two complementary approaches, followed by a synthesis. The use of fuzzy logic and specific resolution of the graph can propose solutions for decomposition of the prototype hybrid into modules.

3.4.2.1 Manufacturing approach

A fuzzy logic manufacturing method is used to find the processes that are best adapted to manufacturing an FC or a group of FCs. During the manufacturing analysis, a feasibility processor had estimated the degree of feasibility of each feature as rated by a process. Thus, each feature was assigned marks during this analysis. The fuzzy logic manufacturing method uses these marks to manufacture the complete FC or group of FCs with the same process, or, if that is not possible, a combination of processes. This combination is evaluated by a fuzzy logic processor.

The manufacturing analysis proposes the best fabrication process for each component of the MCP studied (Figure 8).

The results are incorporated into the representation graph with a graphics code (Erreur : source de la référence non trouvée). This graph is obtained manually in the respect of previous rules.

3.4.2.2 Assembly approach

The AIC fuzzy logic chooses the best adapted AIC for integration of the FC or FC group from a list of parameterized AICs.

After selecting a usable AIC by fuzzy logic, the best AIC is chosen. These three fuzzy logic methods are applied simultaneously. At the end of the iterations, a gatherable hybrid rapid prototype solution is proposed.

An AIC is the identity card of one assembly, which gathers the general characteristics of that assembly. Every AIC has several parameters, which completely define its geometry. It is an informational tool to physically define the assembly between the functional components (FC) of the prototype (Figure 12).

The quality of the interfaces between parts ensures that the assembly requirements of a mechanism are met and that the positioning of the functional surfaces is correct. During the functional tolerancing of an industrial mechanism, designers define the operating mode of the mechanism and impose functional requirements. To formalize the design intentions clearly for each AIC, a method, called TLIC (Tolerancing in Localization with Influence of the Contacts) [17], is used. This method, usually used in mechanics, is applied to the field of RP, and uses positioning tables of the parts to clearly indicate the associated setup surfaces as features, and the ranking of those features. The TLIC [18, 19] algorithm method generates tolerancing of surfaces at the junctions between parts, and gives the contact loop, the active parts, and the corresponding inequality for each requirement. The synthesis of tolerances uses a fuzzy expression of requirements.

Figure 12: Example of an Assembly Identity Card

The results are incorporated into the representation graph (Erreur : source de la référence non trouvée). Each set is an assembly.

The groups represent assembled EFCs, respecting the original specifications.

3.4.2.3 Synthesis

A solution is chosen from the results obtained by the two previous approaches. This solution optimizes the choice of manufacturing process using, for example, a unique process for achieving an EFC. The solution proposes dividing the tooling into five parts (because of the various mold parting surfaces) and five modules (because of the selection processes and the constraints imposed by the specifications) (Erreur : source de la référence non trouvée).

The tool obtained is evolutionary, and its manufacture is optimized in terms of cost and delay by the use of different manufacturing processes (Figure 13).

Figure 13: Final solution

4 Conclusions

A method is proposed for the design and manufacture of hybrid rapid tooling taking into account two points of view:

- The manufacturing point of view, which makes possible the selection of the best manufacturing process to fabricate the modules;

- The assembly point of view, which makes possible the selection of a type of assembly in accordance with the geometric constraints of the tools.

This method is used during the development phase of new products. Then, with the use of evolutionary tools, the time and cost development can be reduced. It can also be used to advantage for the production of parts in series with variations.

Here, the method is applied to injection tooling. It is important to note that it has already been used successfully, on automotive and aeronautical parts, for example, and on plastic and metallic injection molds.

The development of this method is based on an original concept of the Assembly Identity Card (AIC), which completely defines the characteristics of the assembly.

A new representational tool, called the representation graph, includes all the information from the analysis.

Finally, the expertise is formalized using a fuzzy logic-based system.

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