APPROACH TOLERANCE IN THE ASSEMBLIES OF EVOLUTIONARY HYBRID PROTOTYPES

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Abstract

A new answer is proposed to replace the traditional “one shot” prototype (manufactured in one piece with one process): the hybrid rapid prototype. It is used to highly reduce time, cost and increase reactivity during the development times of new products.
The part is decomposed in several components which can quickly be changed and can be manufactured with a process the most adapted.
The main objective of the presented method is to propose an available technological assembly between the different components of the part in the respect of technological and topological function, and initial tolerance.
Using a graph of representation, fuzzy logic and a tolerance point of view, some entities are associated with a CIA (Assembly Identity Card) in accordance with evolutionary and manufacturing analysis. This work will be illustrated by an industrial tooling for plastic injection.

1 INTRODUCTION

1.1 Context

Modern means for the improvement of efficiency in manufacturing are quite diverse. However, the traditional cornerstones, cost, quality and time are the targets that business is managed. Thus, mass customization is one of the modern means to achieve these goals, and allows customizing product to individual clients and producing those with principles of mass production. For many products, the competitive edge of the producer is dependent not merely on the price, but also on the choices or variations provided in each product line. Examples of such products range from automobiles (manifested by the increasing number of "variants" available in any base model of a car) to electronic products such as computers. The challenge is to create a variety of products from a common family without a significant trade-off 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, whose variants are designed to fulfill different customer demands. The variants are created by adding specific components to the platform. The use of a small batch with an alternative is thus an increasingly frequent option.
At the same time, products have become more complex and the development times of products are increasingly long and laborious. In this context, the hybrid rapid prototype is appearing. In this paper the rapid tooling and the prototype part are presented.
The tools can be of evolutionary, for bridge tooling or for small series. The parts can be aspects, geometrical, functional or technological prototypes.

1.2 Related Work

Hybrid rapid prototyping has been presented in some recent papers [1, 2]. Their researches were based on the study of two processes: CNC and Rapid Prototyping (RP) systems. CNC is used when the quality of the part is higher than what it is possible to obtain with RP system. Their methodology uses STEP AP-203 data but didn't take into account ISO specifications of the model. Likewise, concerning the manufacture of the parts, methodology that would allow the decomposition of a part into a space partitioning, was developed [3]. The weakness of these studies is that only build accessibility is considered. A choice of an adequate process is not proposed.

At the same time, the assembly of the hybrid prototypes and its repercussions on the design was never taken into account. These works do not envisage any interaction between manufacture, assembly and design.

Some research about product families [4, 5], and design for assembly [6]] related only the assembly of subset of a product (for example: a power supply). This work does not treat assemblies of cast solid product composed of hybrid elements (for example: injection tooling). In the field of tool-maker, tools are usually made in several components. This decomposition is the result of knowledge of the engineer but there is no reliable method to obtain this decomposition. In this paper, a novelty method is proposed about the design of this kind of tools.

The concept proposed in this paper aims to decompose the part on a Multi Component Prototype (MCP), instead of a part made in one piece. The two main reasons are to include the evolutionary requirement of the prototype regarding to the tests that are performed on it; and to optimize the manufacturing process locally, regarding to the component geometry and functional requirements. Therefore, only one or few components would have to be remanufactured separately, in order to update prototype geometry for testing purposes.

A methodology is proposed for assemble the multi component part by using the extraction and the use of entities from a CAD model.

A new part decomposition for a prototype is proposed in order to guarantee the functionality requirements and to allow the evolutionary of its geometry. Furthermore each component of the new partitioned part is built with the more appropriate process. The assembly of components is design to have the same tested characteristic as the "one piece" part. This new approach is entitled "hybrid evolutionary prototypes". These different analyses are based on CAD STEP specifications and more especially on Application Protocol AP-224. STEP AP-224 is a manufacturing features oriented description. This chapter of ISO 10303 specifies the information needed to define product data necessary for manufacturing a mechanical part. The product data is based on existing part designs that have their shapes represented by machining features. Chapter AP224 contains all of the information and capabilities necessary to manufacture the required part.

2 MCP CONCEPT

2.1 Presentation

MCP concept is presented in the Figure 1. The goals are to allow evolution of parts for testing purpose. All developed methodology is based on feature analysis. For that, automatic feature recognition [7] like in various research works made in CAPP [8], was not used. Step-AP224 entities in the CAD model of the part is used, because it is essential to

have with the geometry several information like tolerances and part proprieties. Afterwards a 3D partitioning of the part is made in Functional Components (FC) (Figure 1).
The result is the definition of all components that create the Multi Components Prototype [7]. The MCP is like a 3D puzzle of the part. After this task, the manufacturing of each component is realized. Various manufacturing processes and materials are chosen for each of them [8]. Then, an assembly of all components is made in order to have experimental testing on MCP. If the results of the tests do not match with the technical requirements, then only one or more components have to be re-designed and re-manufactured in order to have the prototype updated. The use of the MCP concept to re-design and manufacture prototypes, allows the reduction of costs and time for each iteration in the loop. When the test results match with functional requirements, design is then validated.

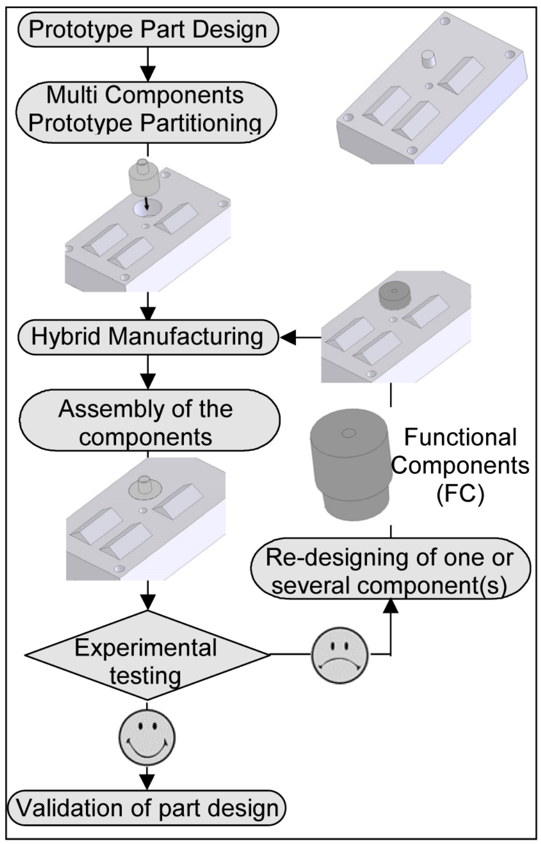


Figure 1: MCP in design activity.

2.2 MCP Activities

MCP concept involves realizing a product from a single piece part. For experimental testing, a MCP must have the same functionality as the single piece prototype from which it comes. Otherwise results could not be interpreted, as it would be on a single piece part. Therefore all activities shown in Figure 2 have to be perfectly analyzed to obtain a Hybrid Rapid Tooling with the same characteristics of its cast solid model.
Each analysis has its own knowledge.
A previous paper [9] detailed the feasibility analysis. The goal is to group entities that participate to the same functions in the same piece of the puzzle. The manufacturing

analysis [10] proposes the best manufacturing process for each component of the studied MCP. Hereafter, the final analyses are developed.

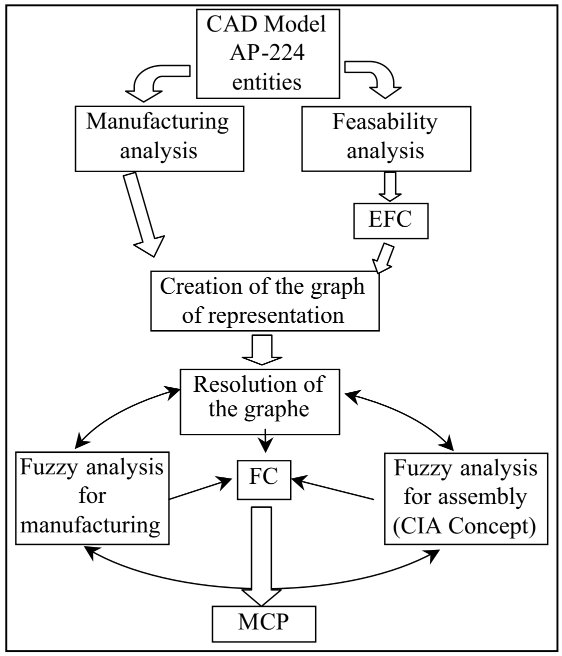


Figure 2: The different activities for MCP concept.

2.3 Method

In the methodology, the F.C concept, presented in chapter 2.1 is applied. A FC is a real component of the hybrid rapid prototype. It is composed with AP-224 feature that participate at the same function regarding to the ISO tolerances (qualitative) and topologic information (Figure 2).

The method is presented on an industrial example. For this product, there are two versions, the version number 1 and the number 2 (Figure 3 and 4). Currently, there are two moulds to manufacture the two version of product. The starting point is Ap-224 entities of the CAD model (Figure 5). This extraction of entities from Ap-224 programs is possible. For example, the commercial software STEP-trans [11] used for obtaining this entities from a CAD model, gives automatically the list of the features Ap-224 on a “simple part”.

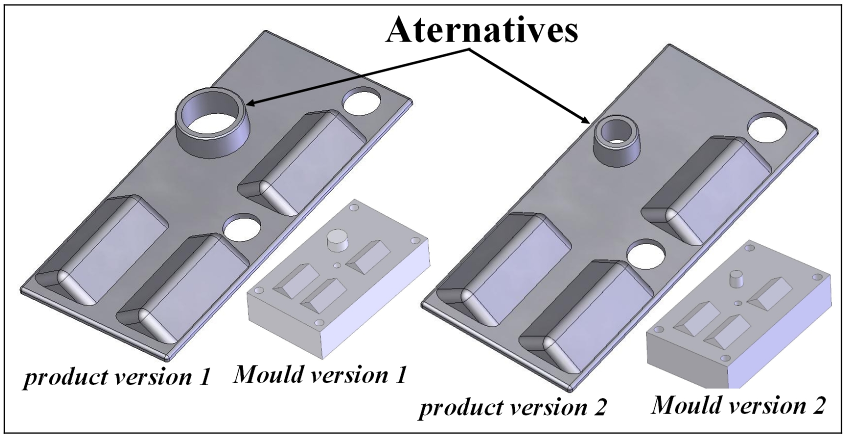


Figure 3: Industrial example (Version 1 & 2).

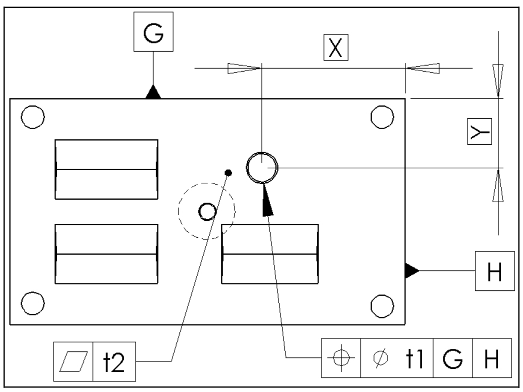


Figure 4: 2D draw with functional requirements only for the entity 6.

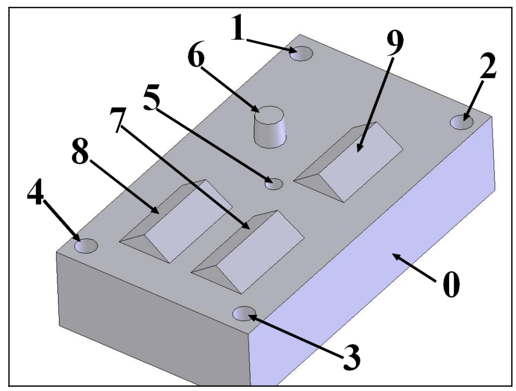


Figure 5: Entities AP-224 mould.

The method is used to obtain a hybrid mould allowing:

- A realization with the best processes.
- The manufacture of the two alternatives products.

Manufacturing analysis

During the manufacturing analysis, each AP-224 entities is analyzed to define the best manufacturing processes to manufacture them. For each studied processes, each entities received marks (1 to 10). Mark 0, if the process is not available to mark 10 if the process is perfectly adaptated to manufacture the entity. [12] To obtain these marks, 4 processor are used. The first treatment occurs with the feasibility processor. It will estimate the feasibility degree of each feature done by a process. The cost processor estimate the manufacturing cost of each feature, without considering "fixed costs". The time processor estimate the manufacturing time of each feature, without considering non-productive times. At the end, Fixed costs and non-productive times are taken into account by the classification processor. This processor gives all modules (features gathered together) with their assigned process, and the global estimated manufacturing time and cost.

Here for example (Figure 6), the entity 5, injection point with conical forms, will be preferably manufactured with EDM Process. Nevertheless, the DMLS process can be used but the HSM process is completely unsuited.

	Manufacturing capability coefficient		
Entities	HSM	EDM	DMLS
0	10	1	1
1	10	5	1
2	10	5	1
3	10	5	1
4	10	5	1
5	0	10	5
6	10	3	7
7	10	5	3
8	10	5	3
9	10	5	3

Figure 6: Manufacturing capability coefficient.

Feasibility analysis

The feasibility analysis analyses functional (ISO specifications), evolutionary criterions and topologic configuration between AP-224 entities of the part. The goal is to group together features that participate to 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 particular topologic configuration, must be in the same FC.
In the example the feasibility analysis, give the AP-224 entities list and their properties, the list and the details of the links between AP-224 entities (see figure 7 a,b).

entity										
0										
1	L1									
2	L2									
3	L3									
4	L4									
5	L5									
6	L6									
7	L7									
8	L8									
9	L9									
	0	1	2	3	4	5	6	7	8	9

(a)

Inclusion	Θ
Contact	Ю
Intersection	∩

	Type	Tolerance
L1	Θ	Low
L2	Θ	Low
L3	Θ	Low
L4	Θ	Low
L5	Θ	High
L6	Ю	Low
L7	Ю	High
L8	Ю	High
L9	Ю	High

(b)

Figure 7: List of the links (a) and Details of the Links (b).

Here for example (Figure 7 a,b), there is the link number 5 between the entity 5 and the Base shape. The type of this link is inclusion. That means that the entity 5 is including in the Base shape. (The volume of entity 5 is completely contained in the volume of the base shape). Following theses stages, a graph of representation is made in accordance with the rules previously defined (Table 1). This graph of representation proposes a cutting of the part in MCP according to the results of the analysis of feasibility (Figure 8).

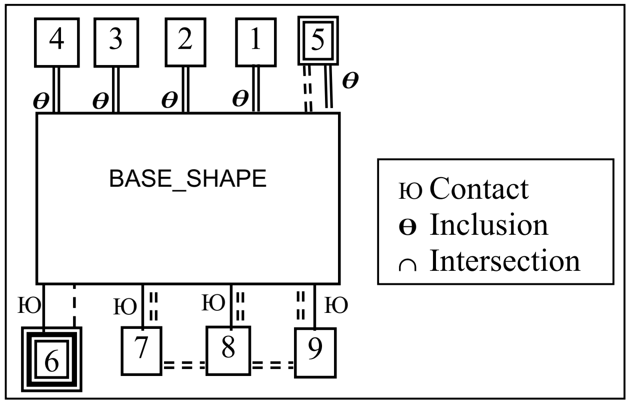


Figure 8: Graph of representation of the example.

A graph of representation

The entities AP-224 extraction, special specification, the functionality constraint product, the manufacturing and feasibility analysis give some important information. With construction rules and special representation (table 1), the graph of representation is used to synthesis these information.

"Breakable" entity without constraint		"Unbreakable" tolerance of strong positioning	
"Unbreakable " entity with functional constraint (sealing...) or evolutionary or geometrical tolerance (high)		Process EDM	
Entity unbreakable because it's evolutionary		Process DMLS	
Weak topological link « breakable » (contact)	—	Process HSM	
Strong topological link « unbreakable » (intersection, inclusion) or particular specification	=	Multi process (example HSM and DMLS possible)	
Link defining a FC (group of entity) resulting from the analysis of feasibility	≡	Entity "unbreakable" constraints by a link tolerance of strong positioning	
"Breakable" tolerance of weak positioning	- - -		

Table 1: Captions.

The resolution of the graph representation is used to gather the FC in the respect of the "functionality" of the part. This resolution is based on few rules (table 2).

Resolution Rules : 1/ The FC containing an evolutionary entity must be smallest as possible (i.e. to contain less possible entity) 2/ A regrouping does not cut a double Line (Unbreakable) 3/ The MCP must be compose at least of Possible FC. Possible

Table 2: Resolution Rules.

If possible, the evolutionary FC doesn't be gathered. In fact, it will be changed during the tests or during alternative production. The objective is to have a minimum number of components for the Hybrid rapid prototype. In this stage the information contained in the link between AP-224 Entities are used.
For the example, the graph of representation (figure 8) is obtained.

Fuzzy logic analysis for manufacturing.

A manufacturing fuzzy logic method is used to find the processes the most adapted to manufacturing FC or FC groups. During the manufacturing analysis, made before, a feasibility processor estimates the feasibility degree of each feature done by a process. Thus, each feature obtained marks during this analysis. The manufacturing fuzzy logic method use this marks. The objective is to manufacture the complete FC or FC groups with the same process, or if it is not possible to have an available combination of processes. This combination is evaluated by fuzzy logic processor. In the example (Figure 9.) the entities of FC1 are preferably manufactured with HSM process expect the entities 5 witch is preferably manufactured with EDM. In this case the two processes are used successively.
The manufacturing analysis proposes the best manufacturing process for each component of the studied MCP. (Figure 6)

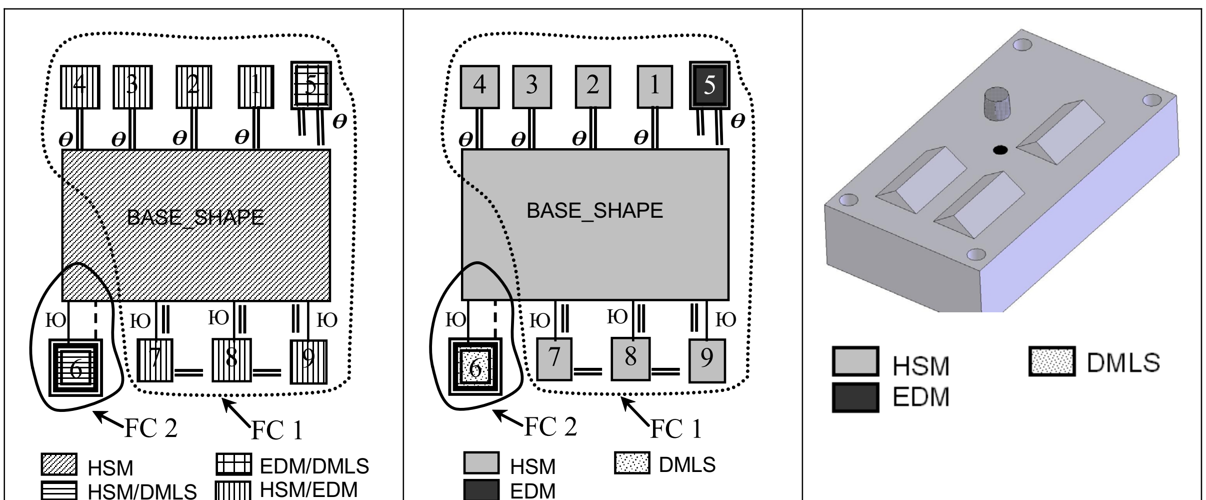


Figure 9: Manufacturing fuzzy logic method.

Fuzzy logic analysis for assembly (CIA Concept)

The CIA fuzzy logic chooses in a list of the parameterized CIA, the most adapted CIA for integration of the FC or FC group.
After the choice of usable CIA by fuzzy logic, the best CIA is chosen. These three fuzzy logic methods are used simultaneously. At the end of the iterations a solution of gatherable Hybrid rapid prototype is proposed. To manufacture the various alternatives of the product, the CIA 1 is replaced by the CIA2. (Figure 10)

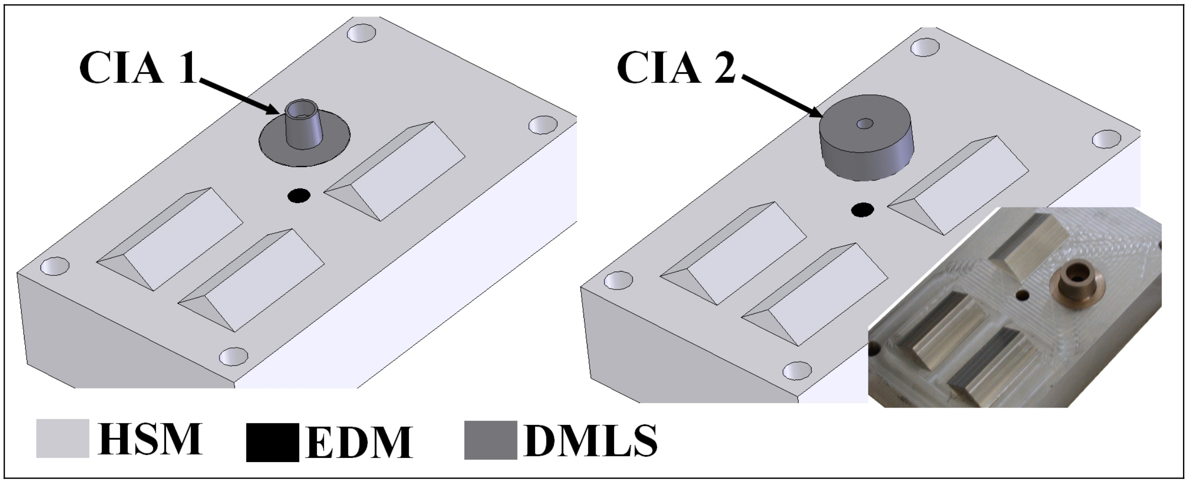


Figure 10: Proposed solution.

In the following chapter the tolerance point of view of the CIA assembly is developed.

3 ASSEMBLY DESIGN AND TOLERANCE POINT OF VIEW

3.1 Introduction

The main objective of this analysis is to propose an available technological assembly between the different components of MCP. For this, standard assemblies (noted CIA (assembly identity card)) have been defined. Each standard assembly is parameterized by its CIA. It is necessary to associate via fuzzy logic, for each entity a completely definite assembly in order to obtain technological solution of MCP.

3.2 CIA Concept

A CIA is an identity card of one assembly, which gathers the general characteristics of this assembly. Each CIA has several parameters, witch completely defines its geometry. The CIA is an informational tool to define physically the assembly between the functional components (FC) of the prototype.
The quality of the interfaces between parts ensures the assembly requirements of a mechanism and the right positioning of functional surfaces. During functional tolerancing of an industrial mechanism, designers define the operating mode of the mechanism and impose functional requirements. To formalize the design intents clearly for each CIA, a method, named TLIC (Tolerancing in Localization with Influence of the Contacts) [13], is used. This method usually used in mechanics is applied to the field of Rapid Prototyping. This method uses positioning tables of the parts to clearly indicate the set up surfaces

associated as features and the preponderance order of the features. Algorithms of TLIC [14, 15] method generate tolerancing of surfaces of junction between parts and give, for each requirement, the loop of contacts, the active parts and the corresponding inequation. The synthesis of tolerances uses fuzzy expression of requirements. (Figure 3 and 4).

From a 2D draw (Figure 4), the fuzzy logic analysis for assembly (the CIA fuzzy logic) chooses in a list of the parameterized CIA, the most adapted CIA for integration of the FC or FC group. In this data base, each CIA has tolerances to respect the functional CIA requirements (figure 11 and 12). After this choice, the TLIC method [16] is used to take into account the functional product requirements. (figure 4). Then the CIA is completely define. (Figure 13).

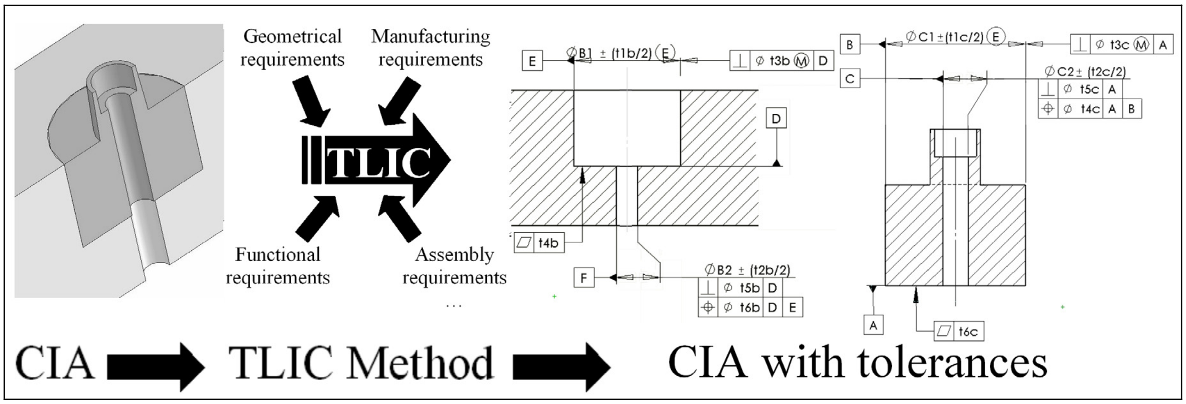
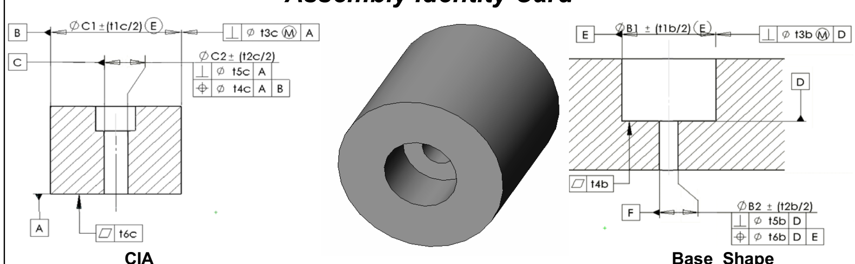


Figure 11: TLIC Method.

Assembly Identity Card



∅ C1	Value	t1c	Value	_ C6		t6c	Value	∅ B1	Value	t1b	Value	_ B6		t6b	Value
∅ C2	Value	t2c	Value	_ C7		t7c		∅ B2	Value	t2b	Value	_ B7		t7b	
_ C3		t3c	Value	_ C8		t8c		_ B3		t3b	Value	_ B8		t8b	
_ C4		t4c	Value	_ C9		t9c		_ B4		t4b	Value	_ B9		t9b	
_ C5		t5c	Value	_ C10		t9c		_ B5		t5b	Value	_ B10		t9b	

degree of freedom numbers	1	Material	Value
can be Dismantled / can't be dismantled	Can be	Mechanical strength (Re)	Value
difficulty of disassembling	1	Melting point	Value
direct or indirect link	direct	dilation coefficient	Value
grip or Obstacle	Obstacle	Thermal Conductivity	Value
Number of screw	1	Porosity	Value
Manufacturing process	Value	Manufacturing cost level	Value
Ra	Value	Manufacturing difficulty level	Value
dimensional quality	Value	Assembly cost level	Value
Quality of positioning	Value	General form (cylindrical, parallepipedic.	Value

Figure 12: Example of Assembly Identity Card.

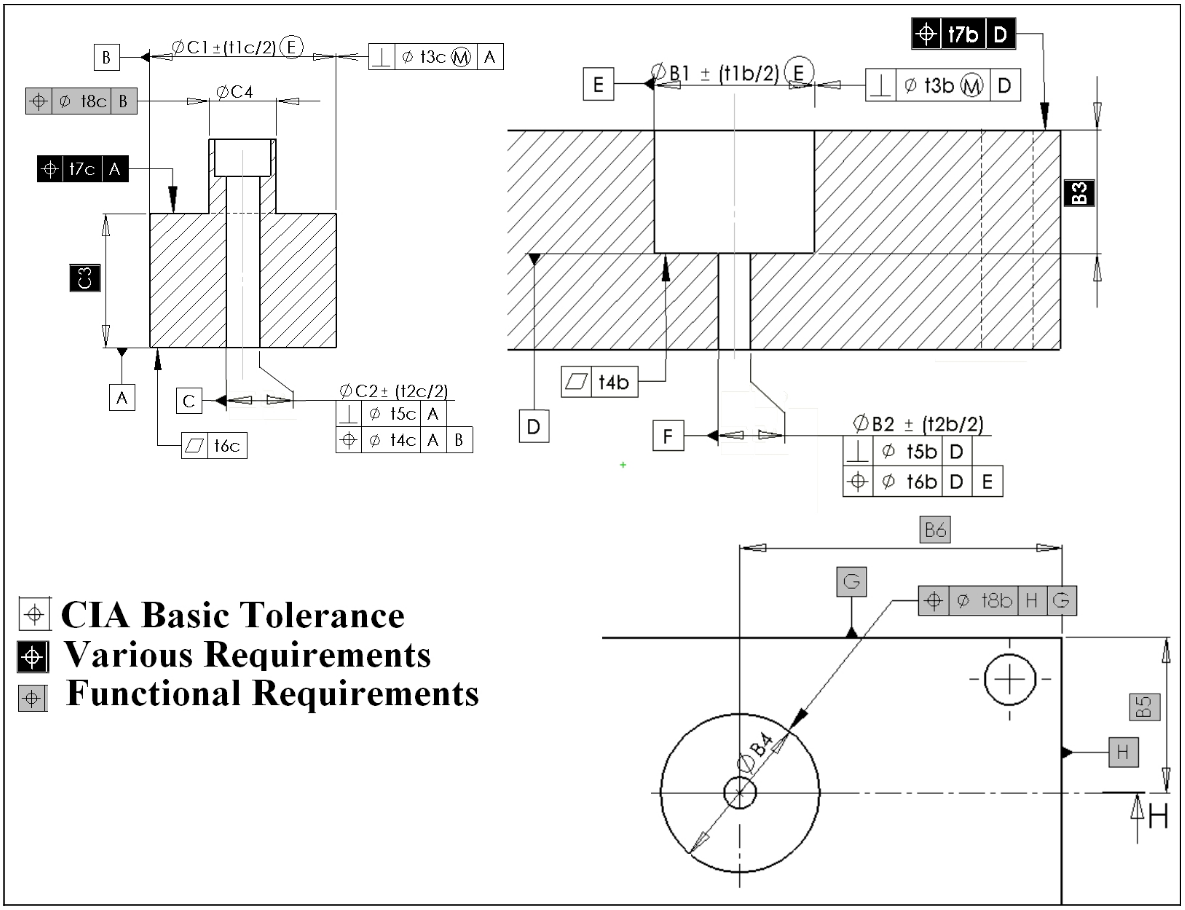


Figure 13: Design drawing.

The fuzzy logic analysis chooses the most adaptated CIA for integration of the FC. This CIA, must take into account the functional product requirement defined by the designer during the conception. The fuzzy logic approach compares the design drawing requirements with the CIA capability informed in the Assembly identity card (Figure 12).

This method with tolerance point of view gives some interesting solutions. The TLIC method, usually used in mechanism, is used to obtain the tolerance of CIA in the field of Rapid Prototyping. For this, some adaptations are made on the original TLIC method. First of all, each CIA has dedicated tolerancing. After, in accordance with functional specifications of the part, each assembly between the different components is calculated with a specific method developed by the team. Finally, the numerical value of tolerance for complete assembly (Base_shape and components) is obtained.

4 CONCLUSION

This method takes place during the product development. It allows to reduce consequently time and cost when complex prototype must be manufactured and optimized.
This methodology uses multiple point of view and knowledge to analyze prototypes definitions. The assembly and geometrical analysis based on 2 different Fuzzy logic

processes, give FC groups. These groups are associated with a CIA in accordance with evolutionary and manufacturing analysis. The TLIC Method is directly used for tolerancing the CIA. The Hybrid Rapid Tools are composed by the assembly of different CIA with the base shape.

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