AN ADAPTIVE TOLERANCE MODEL FOR COLLABORATIVE DESIGN

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To ensure the robustness of geometric tolerancing in collaborative design, a multi-view tolerance data representation is needed as well as a multi-level representation. The goal of multi-level representation is to detail the tolerances as the knowledge of the product progresses during its development.
After a brief discussion, IPPOP product model and GeoSpelling tolerance model are chosen as basis of definition and implementation of an adaptive tolerance model. In this model, the multi-level and multi-view capabilities are permitted by level and view adaptations. Level and view adaptations consist in an evolution of the viewable tolerance data according to the step of design and to the actors.
These adaptations are presented and applied on a part of an automated cutting machine for fabrics.

1. INTRODUCTION

In the global product development process, geometrical tolerancing should take a major role. In fact, geometrical tolerancing, as geometrical modeling, is an important way of collaboration between the actors of the lifecycle of the product. Tolerancing leads to many data from the expression of the functional requirements to the maintenance, including conceptual design, embodiment design, detail design, manufacturing and control. However, most of the commercial tolerancing tools are not able to share data with other expertises such as functional analysis, manufacturing and metrology.

In the context of digital enterprise:

- the tolerance expression must be formalized to be integrated in a product model,
- the tolerance expression must be adapted to conceptual design until detail design (multi-level),
- the tolerance expression must be adapted to each activities of the enterprise such as design, manufacturing, metrology, control, maintenance (multi-view).

For that, a global framework is stated by the choice of a product model and of a tolerance model. Then, the paper develops how the integration of the tolerance model chosen allows adaptation during the product development.

2. PRODUCT MODEL FOR TOLERANCING

2.1 Context

In digital enterprise context, a data structure is necessary to ensure the management of the product lifecycle, including the management of tolerancing. Several product models have been developed to take up this challenge (Summers, 2001). One major consequence is that the kernel of a product model can not be a geometric model traditionally used by the commercial CAD systems (Noel, 2004).

Current product models are dedicated either to generic product description along its design cycle or to a specific expertise. On one hand, the entities used in generic product model have a semantic which can ease the dialog between the actors of the design cycle, nevertheless, the semantic of these entities is too poor to ensure the robustness of the knowledge of a particular expertise (Krause, 1993) (Yoshikawa, 1994) (Tichkiewitch, 1996). On the other hand, a product model specific to one expertise (Salomons, 1996) (Johannesson, 2000) can not be used in digital enterprise context. In consequence we purpose the use IPPOP product model in this paper.

The authors have participated to IPPOP project (Integration of Product, Process and Organization for Performance Enhancement in engineering) which the goals are to develop and set up an appropriate environment for collaborative design including management and coordination (Girard, 2004).

The product model developed for IPPOP (Noel, 2004) formalizes the technological knowledge about product (function, structure, behavior, expert view, etc.). Particularly, IPPOP product model supports the product description all along the design cycle with various expert points of view . For that, the semantic of IPPOP entities can evolve during the design. The implementation in object oriented language facilitates this evolution. Dufaure and Teissandier have presented an application of IPPOP product model in the tolerancing context (Dufaure, 2004).

2.2 IPPOP product model

To ease the use of computer aided design tools in a collaborative context, IPPOP product model is based on three main objects: component, interface and function (In Figure 1, the shape of the three objects are distinguished for a better understanding of the next figures). These three objects allow to support both functional and structural descriptions of products.

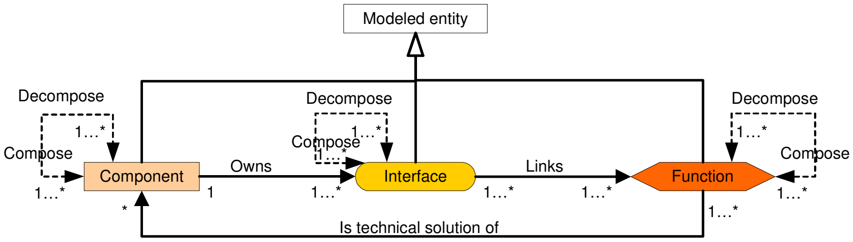


Figure 1 – Objects and relationships of IPPOP product model

Component instances describe the product in terms of assemblies, sub-assemblies and parts. Each component can be decomposed into several ones to contribute to the description of the product structure.

Interface instances allow to describe the geometric elements of a component which are in relation with the external medium. The links between component and interface instances signifies that one component owns one or several interfaces. Component and interface instances represent the structural decomposition of the product at one particular stage.

Function instances describe the relation between interfaces. A function represents a functional requirement on the product or a contact condition between interfaces. The semantic of these relationships is that a function instance links together one or several interface instances. The decomposition related to a function instance allows to describe the functional description of the product.

The relationships between structural and functional descriptions of a product are realized by the relationships between interface and function instances of the product.

2.3 Tolerancing as a function

Compared to current product models, the tolerances are not simple attributes of geometrical instances or specific objects, but are considered at the same level as functional or technical requirements of the product. Geometrical tolerances are particular specifications among all the product requirements.

For IPPOP product model, the requirements link interfaces and are classified in the functions. In consequence, as geometrical tolerances are requirements, they link also interfaces. A location of a plane, with respect to a cylinder, is defined as a function instance in relation with the plane interface and the cylinder interface.

The advantage of merging requirements and tolerances is that a functional requirement in conceptual design or a geometric specification in detail design are described by the same type of object. As the object is unique, the management of the instances and the traceability of the functional data during the design cycle are easier.

3. TOLERANCE REPRESENTATION

As the product model is defined, the tolerance representation has to be discussed; the existing tolerance models and their particularities are briefly presented, then the adaptive model is developed.

As Salomons et al wrote, representation and specification of the tolerances can be clearly distinguished (Salomons, 1996). The presented paper develops the tolerance representation in the enterprise context.

One of the earlier important research paper on tolerance representation is due to Requicha (Requicha, 1983). In his approach, a tolerance zone is described as a global offset zone. Since this work, a significant amount of research has been devoted to the development of specification models distinguished between:

- parametric models (Turner, 1990) (Wirtz, 1991) (Gaunet, 1993),
- boundary models (Jayaraman, 1989) (Robinson, 1998).

Standards have also greatly evolved during this period (ISO GPS). Mathematical expressions of the standardized tolerances have been developed (ASME Y14.5.1M, 1994). More recently ISO (ISO/TS 17450-1, 2005) gave a more general framework based on the GeoSpelling model. The GeoSpelling model attempts to formalize the tolerance representation and to answer to the needs of tolerance expressions in the enterprise (Mathieu, 2003). GeoSpelling model introduces a tolerance semantic (for standardized tolerance or not), ensuring quite all the current needs. In GeoSpelling, a specification is defined as a characteristic on features defined by operations.

Sudarsan et al. (Sudarsan 2005) suggested to integrate ISO standards in a general product model. Some CAD systems begin to integrate the specification syntax (Functional Tolerancing and Annotation, FTA in CATIA), and STEP standard defines an exchange language between CAD systems (ISO 10303-47, 1997), nevertheless, the semantic leaves fairly poor. In this work, a more reach syntax is integrated in IPPOP product model on the basis of the GeoSpelling concepts.

4. ADAPTIVE TOLERANCE MODEL

4.1 Principles

To adapt tolerances according to the evolution of the product during its lifecycle, the tolerances are defined with different levels of detail. In some cases, at the beginning of product development, top level details can be sufficient. If an expert need more information, the tolerances may be detailed. According to the evolution of the product during its lifecycle, tolerance may be more or less detailed, it is named **detail adaptation** (Figure 2).

To adapt tolerances according to the activities, a tolerance may be seen according to different views. For example, a tolerance can be shared distinguishing the nature of the toleranced features (integral or extracted), the criteria of association of a datum feature (minimax or least-squares). The adaptation to different views is assumed by the multi-view system integrated in IPPOP model, it is named **view adaptation** (Figure 2).

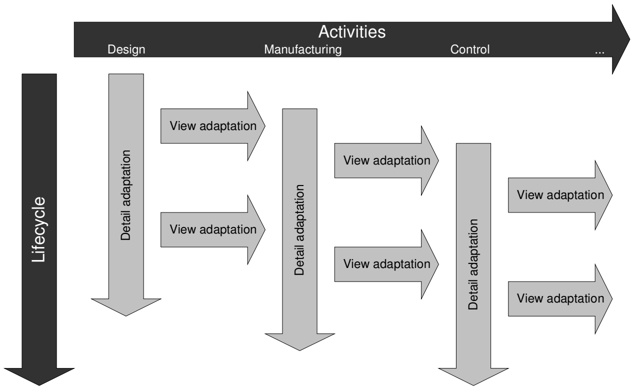


Figure 2 – Detail and view adaptations

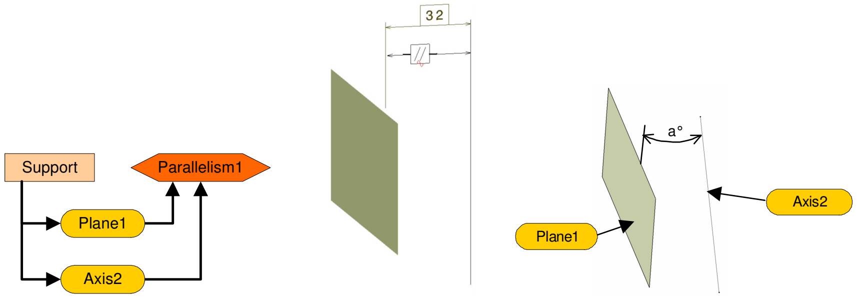
In the following, an example illustrates these adaptations. We must pay attention to the fact that three models of the tolerances are used: the product model, the nominal model and the geometrical model with defaults. In the **product model**, the tolerance is presented under the form of instances of the model, that corresponds to records in the database. In the **nominal model**, the tolerance is presented as symbols on nominal geometry, that is what the designer can see in the CAD viewer. In the **geometrical model with defaults**, the semantic of the tolerance is explained by a drawing representing the defaults of the geometry, that represents what the designer has to imagined when he writes or reads a tolerance in the CAD viewer. These three models are represented respectively by a diagram and two drawings.

4.2 Detail adaptation

Let us consider a support of the cutting head of an automated cutting machine for fabrics, the designer knows that the axis of the cutting head has to be parallel to a contact plane, at a distance of 32mm.

At this stage, a parallelism tolerance and a location tolerance are defined. *Plane1* and *axis2* are interfaces of the *Support* component, and the *Parallelism1* tolerance links the interfaces (figure 3.a). The interfaces may be represented as a skeleton in the CAD system, with a non–standardized tolerance (figure 3.b). In the CAD system, the skeleton consists in a plane and an axis respecting the constraints of parallelism and distance.

Until now, the type and dimensions of the surfaces of the part are unknown, the tolerances are parametric tolerances on the ideal features of the skeleton (figure 3.c). The tolerance data may be extracted by an API toward a tolerance analysis software permitting to already quantify the tolerance values.

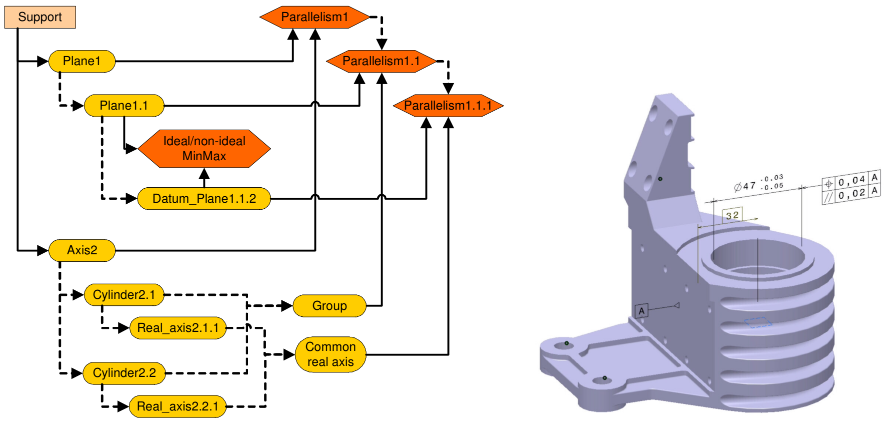


a) Product model b) Nominal model c) Geometrical model with default

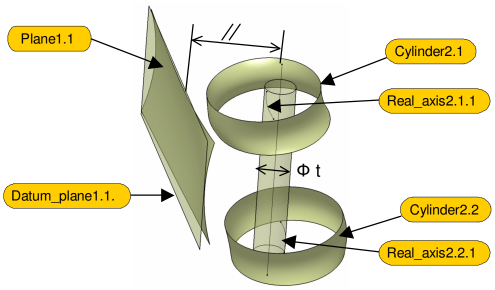
Figure 3 – Tolerance on skeleton

When the technical solutions are known, surfaces may be defined. Here, the axis is materialized by two bearings. At this stage, the tolerances may be detailed, the *Parallelism1.1* concerns the contact plane and the group made up of the two cylinders, corresponding to the housings of the ball bearings. *Parallelism1.1*, *Plane1.1*, *Cylinder2.1* and *Cylinder2.2* are decomposed instances, respectively from *Parallelism1*, *Plane1* and *Axis2*. This is the first step of detail adaptation, *Parallelism1*, *Plane1* and *Axis2* are detailed trough this decomposition.

The geometrical and tolerance data may be accessed by the manufacturer to start the definition of the process planning and the verification of the feasibility of the tolerances.



a) Product model b) Nominal model



c) Geometrical model with default

Figure 4 – ISO GPS tolerance

In a last step, the part is completely defined in the CAD system and the final tolerances are defined by ISO GPS tolerances (figure 4.b). The meaning of the tolerances can be completely defined as in figure 4.c. The product model is adapted by detailing the toleranced features and the datum features. In the example (figure 4.a), the toleranced feature is made up of the composition of two real axes, *Real_axis2.1.1* and *Real_axis2.2.1*, and the datum feature *Datum_plane1.1.2* is an ideal plane tangent to *Plane1.1* (non-ideal plane). The contact is represented by a function instance *Ideal/non ideal* (figure 4.a) which links the two surfaces, attributes of this function instance may detail the criteria of association. It points out the fact that function instances are used generally to make a relation between interfaces as requirement, tolerance, joint, datum association, …

The different instances are specialized by attributes. These attributes allow to define type and band width of filters, association criteria, … As design is evolving, adaptive tolerance model permits to integrate more and more details.

4.3 View adaptation

The second type of adaptation is view adaptation. IPPOP product model allows to specialized a modeled instance (component, interface or function) in different views. Multi-view is particularly efficient for collaborative activities, and tolerances are used in different activities, principally in design, manufacturing and control.

To control the parallelism in coordinate metrology, the first difference with design is that the controlled tolerance is based on measured points. *Plane1.1* is measured in a finite number of point. This set of points is a particular view of the plane, denoted extracted plane, *Extracted_plane1.1.2*. To detail *Extracted_plane1.1.2*, attributes may define sampling strategy, number of points, density of points, … Similarly, the real axis cannot be measured, only points on sections may be measured, providing centers of sections. In the same manner, attributes may define how the measured points are chosen and how the section centers are computed.

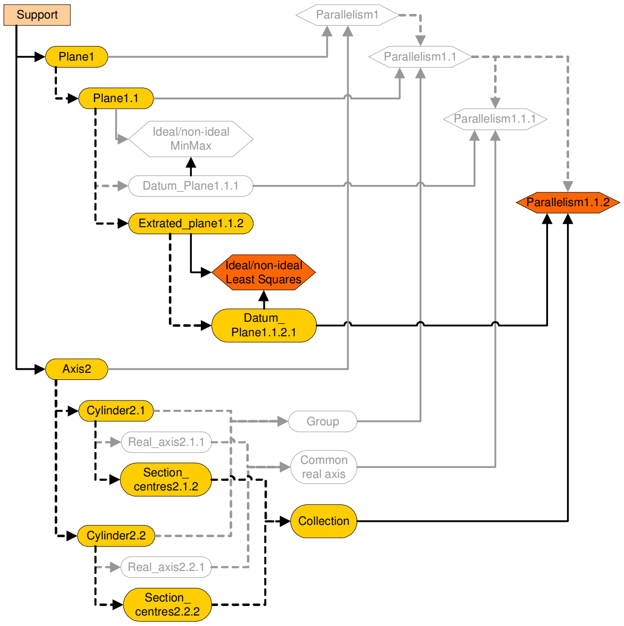


Figure 5 – Control tolerance view (design view is in pale grey)

The second difference is the dependence with the metrology software used. Indeed, the metrology software do not furnish every geometrical operations defined by the GPS standards. In this case, another operation must be used, the "nearest" operation. As example, for the association of a datum plane, the minimax criterion does not exist in every software, instead of it, the least squares criterion is used.

Figure 5 represents the control view of the parallelism and the design view is represented in pale grey. IPPOP product model permits to define these views and to pick a particular view.

5. CONCLUSION

The tolerances are among the most often shared data between the activities all along the lifecycle. They must be adaptive in detail to follow project development and must be adaptive in view to be shared between activities. The proposed model integrated in IPPOP product model allows these adaptations. One expert can detail a tolerance representation all along his activity, and another one can specialize a shared tolerance representation to adapt it to his own point of view. This adaptive model facilitates the traceability of the tolerances.

For an easy understanding of the paper, the example concerns a single part, but the concepts presented allow to take into account assemblies, even if ISO tolerances do not yet include assembly tolerances.

IPPOP project is a national project and it is encouraged by French industry and research ministry in the framework of RNTL program. More information are available on the website http://ippop.laps.u-bordeaux1.fr.

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