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Paper:

Current Situation and Problems for Representation of Tolerance and Surface Texture in 3D CAD Model

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This paper explores current problems in representing of tolerances and surface textures in 3D computer-aided design (CAD) models. Today, all available 3D product data, such as dimensioning and tolerance, are not used in digital form throughout the product development processes. Tolerance and surface texture data for product are very important in design data. In downstream processes, such as process planning and manufacturing, such data are referenced to determine machining processes and process parameters. In inspection, such data provide criteria for verifying functionality of the machined product based on measurement results. Previously, such data were communicated using 2D drawing and not included in 3D CAD data.3D models are widely used and demand is increasing for the annotations in 3D model, e.g., standard for the digital product definition data practices was developed by ISO, and the guidelines for 3D drawing were developed by the automobile industry. This paper explores needs and requirements of tolerance and surface texture representations which are associated with 3D CAD data in product development processes, together with current status, problems, and future works in representing tolerances and surface textures associated with 3D CAD data.

Keywords: tolerances, surface texture, 3D CAD, representation, 3D drawing

1. Introduction

In current product development processes, the need is growing for frequent communication of product data between digital tools such as computer-aided design (CAD), manufacturing (CAM), process planning (CAPP), and engineering (CAE). Articulately linking design, manufacturing, and inspection requires interoperable digital tools representing information semantics independent of implementations.

In current product development process data flow, shown in **Fig. 1**, CAD data and drawings are generated from product requirements using CAD software. In process planning, NC data and instructions are generated from CAD data, drawings, and machining databases using CAM software. In machining, products are generated from raw materials, numerical control (NC) data, and instructions on NC machine tools. In inspection, products are measured on Coordinate Measuring Machines (CMM) and compared to the drawings. However, all available 3D product data, such as dimensioning and tolerance data, are not used in digital form throughout product development processes. Then, the design, manufacturing, and inspection software systems are not interoperable across software ownership boundaries. Typical examples are tolerance data and surface texture data. Tolerance and surface texture data for the product are very important in design. In downstream processes, such as process planning and manufacturing, such data serve as references for determining processes and process parameters. In inspection, such data serve as criteria for verifying functionality of the machined product based on measurement results. Such data have been conventionally conveyed by 2D drawing data and not included in 3D CAD data.

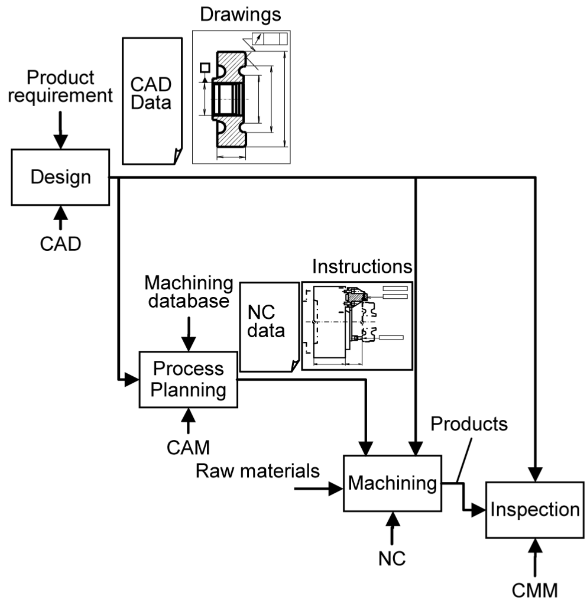

Fig. 1. Product data in product development process.

With 3D models now used almost anywhere, demand is growing for 3D model annotation, e.g., standard for the digital product definition data practices was developed by ISO [1], and the guidelines for 3D drawing was developed by the automobile industry.

The following sections explore the needs and require-

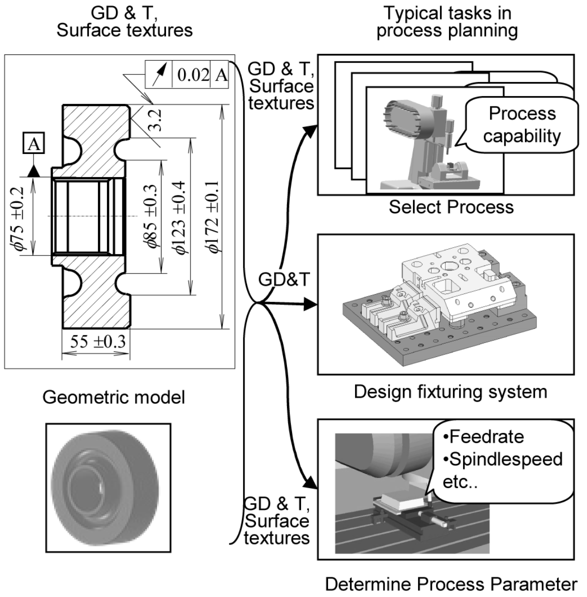

Fig. 2. Typical process planning tasks using dimension, tolerance, surface texture and 3D geometric model data.

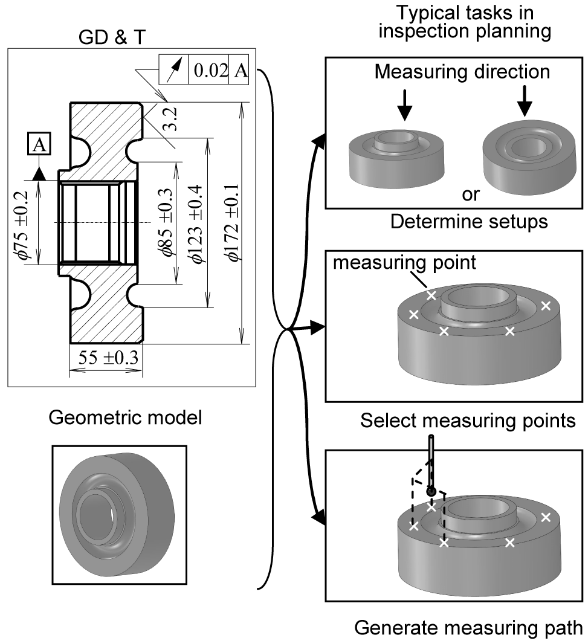

Fig. 3. Typical inspection planning tasks using dimension, tolerance, surface texture and 3D geometric model data.

ments of tolerances and surface textures representation associated with 3D CAD data in product development processes, together with current status, issues, and future works.

2. Needs of Dimensions, Tolerance and Surface Texture in Downstream Processes

2.1. Needs of the Dimensions, Tolerances, and Surface Textures in Process Planning

In process planning, geometric dimensioning and tolerancing (GD&T) information and surface textures are important in tasks as shown in **Fig. 2**.

In addition to shape, individual processes have intrinsic process capabilities about GD&T and surface textures constraining to process selection [2].

Fixture design, for example, primarily depends on machining forces applied to the component, available grip surfaces, material properties, product tolerance requirements, and available fixturing components such as locators and fixturing schemes. Tolerance specifications of the product determine fixture precision [3].

Micro process planning determines a combination of spindle speed, depth of cut, and feed for achieving specific surface texture. Different materials affect machining parameters for obtaining same product roughness Some research works establish the model of the relationship between machining parameters and surface texture [4]. CAPP determines optimal machining parameters from these models and surface texture data.

Process planning using computer tools requires inputting the information on dimensions, tolerances and surface textures in digital data.

2.2. Needs of the Dimensions, Tolerance, Surface Texture, and 3D Geometric Model Data in Inspection Planning

Inspection process planning is integral to design and inspection, typically involving tasks using GD&T, surface texture, and 3D geometric model data shown in **Fig. 3**.

Based on research by Zhao et al. [5], automatic inspection planning may be high level (macro) inspection planning for producing collections of setups or low-level (micro). Individual set-up is related to the accessibility of features to be inspected, probes used to inspect individual features, and relative part orientation, so, both GD&T and geometric models are needed in macro inspection planning.

Micro planning consists mainly of point selection, path generation, and executable code generation. The inspection processes carried out on CMMs or on-machine measuring often use touch probes for point-to-point movement when recording 3D workpiece coordinates. Measuring points for each inspection area are decided based on tolerance, geometric features, and desired confidence levels. This also requires information on tolerance and part geometry. Probe-path generation requires collision-free probe-path inspection. Measured parts have geometry similar to designed part, so 3D geometric models are used to generate collision-free measurement paths.

Inspection process planning using computer tools requires inputting the information on dimensions, tolerances and surface textures in digital data.

3. Current Status of Dimensions, Tolerance, and Surface Texture Representation

3.1. Digital Product Definition Data Practices

The standards for Digital product definition data practices such as ASME Y14.41-2003 [6] and ISO 16792:2006 [1] specify requirements for preparing, revising, and presenting of digital product definition data. It supports two applications – model-only, and models and drawings. The models and drawings mean that 3D CAD data do not contain some necessary information, but available engineering drawing. Model only means that the requirements and interpretation of products can be obtained using CAD data without engineering drawings.

An example of 3D GD&T presentation to a part is shown in **Fig. 4**. This standard is to be the basis for presenting GD&T information and GD&T information representation requirement.

3.2. Geometrical Product Specification Standards

Geometrical product specification (GPS) tools are dynamically changing and continuously improving [7]. Basic demand of the new GPS approach is unambiguous definition of a workpiece through the entire production process. The basic tools for GPS are given in ISO/TS 17450. The important concepts of specification and verification procedures in the product development process are addressed in ISO/TS 17450-1 [8]. This GPS duality principle of the specification and verification procedures is shown in **Fig. 5**. Specification operators are formulated as virtual measurement procedures. Verification operators define the operating sequence used during the measurement process. These standards are to become the basis of product definition and inspection semantics for machined products.

3.3. Product Manufacturing Information Data

Product manufacturing information (PMI) conveys non-geometric attributes in 3D CAD and collaborative product development systems required for manufacturing product components or subsystems [9]. Basically, the new GPS approach demands unambiguous workpiece definitions through the entire production process. PMI may include geometric dimensions and tolerances, 3D annotation (text) and dimensions, surface finish, and material specifications. Some applications can be handled the PMI data. Adobe Systems displays PMI data from almost any CAD application. Siemens JT displays annotation in conventional 2D drawings. The PMI data are visualized within the 3D model by CAD/CAM or using 3D Product visualization tools. However, 3D model formats are required for enabling CAM software to access PMI directly for CNC programming, tolerance analysis and CMM software applications.

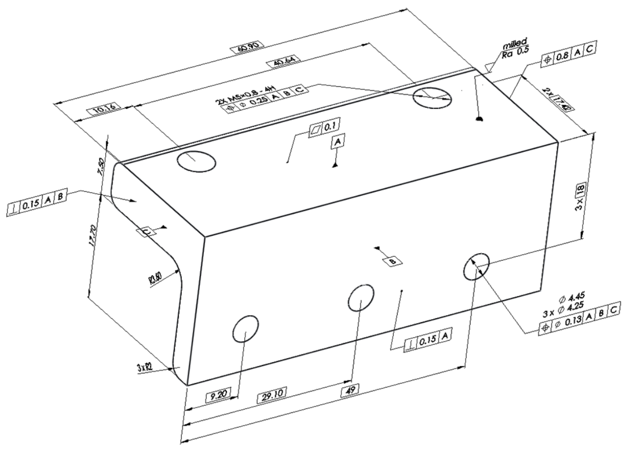

Fig. 4. Example of 3D presentation of GD&T for a part [6].

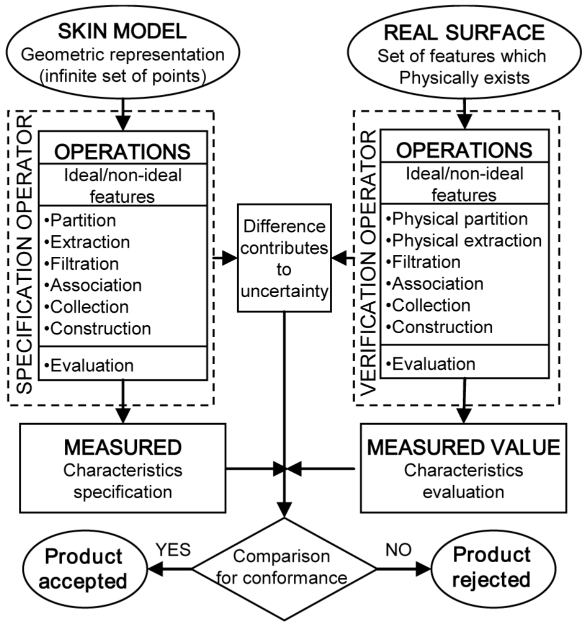

Fig. 5. GPS duality principle for specification and verification procedures [7].

4. Issues and Future Works in Representation of Dimensions, Tolerance, and Surface Texture

One issue pointed out by Srinivasan [10] is GD&T data presentation and representation. It is important to distinguish between 3D annotation data representation and its presentation as shown in **Fig. 6**. Presentation standards such as ASME Y14.41 and ISO 16792, deal only with GD&T visualization aspects, but advanced CAD represents GD&T information internally as attributes and relationships associated with geometrical elements and features based on its internal information model. Both representation and presentation standards are important for product data exchange so that product data are interpretable by both human and computers.

The standard for the representation of 3D geometry

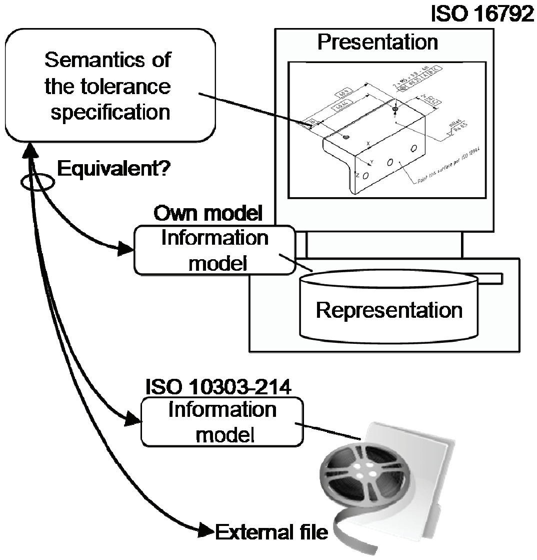

Fig. 6. 3D annotation presentation and representation.

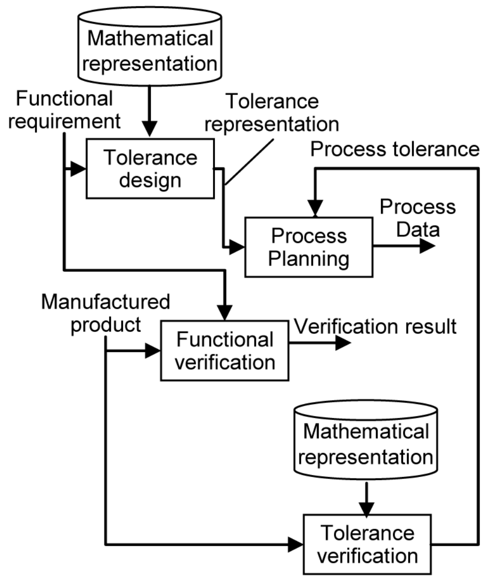

Fig. 7. Ideal processes and models in tolerance-related product development processes.

with GD&T is ISO 10303-214 conformance classes CC12 to CC15, CC19, and CC20 [11]. It must be clarified, however, whether tolerance specification semantics based on GPS standards is equivalent to the 10303-214 information model. Exchange data are based on an ISO 10303-214 information model subset, therefore, it is necessary to clarify whether tolerance specification semantics is equivalent to exchange data files.

Another issue is GD&T and surface texture mathematical and information model related to 3D CAD data in the product development process. Ideal processes and models in tolerance-related product development process are shown in **Fig. 7**. Tolerance specification, analysis, and synthesis are sub-activities of tolerance design [12]. Tolerance synthesis is a tolerance allocation and a tolerance optimization that takes into account the manufacturing and inspection aspects. In tolerance analysis, parts tolerances are all known and resulting geometrical requirements are calculated. To verify geometrical requirements, a mathematical representation of this requirement and of tolerances is needed because all tolerance analysis is based on displacement modeling. In process planning, process data are generated from tolerance representation data based on process tolerance data, so tolerance representation information model should reflect function, inspection, and manufacturing viewpoints.

Tolerance verification defines inspection plans and metrological procedures for functional requirements, functional specifications and manufacturing specifications, but functional verification and manufacturing verification must be separated because reference models for these activities are different.

5. Conclusions

The needs and requirements of tolerance and surface texture representation associated with 3D CAD data in product development processes has been reviewed, together with current status, issues, and future works in tolerance and surface textures representation associated with 3D CAD data.

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