MBD- and GPS-based Workpiece Coordinate Measuring Information Representation Modeling

Jiangyan Jin, Xiaoyang Liu, Yixiang Fang, and Zhenyu Liu

***Abstract*—Measuring information representation modeling seeks normative representation of relevant information in the workpiece coordinate measuring and serves as the theoretical foundation of measuring information extraction and Computer-Aided Inspection Planning (CAIP). Model-Based Definition (MBD) technology represents the latest development of CAD technology and new-generation Geometrical Product Specifications(new-generation GPS) under development is one of the most important technical standards in the product manufacturing field, both providing workpiece coordinate measuring information description and representation with the technological environment and application requirements different from before. In this paper, regarding the MBD dataset of workpieces and coordinate measuring requirements, in combination with the surface model and the geometrical feature defined as the geometrical representation model in new-generation GPS, tolerance items, geometrical features, and model datum/coordinate system are considered as constituents of measuring information. Out of the categorization of the surface model and the geometrical feature by invariance class, relevant measuring features are defined through tolerance annotations. Measuring information representation modeling is to express constituents of measuring information and their relationship. This paper also presents the process of relevant measuring information extraction based on the measuring information representation model and verifies the rationality of relevant modeling representation and the feasibility of the extraction flow using an instance.**

***Index Terms*—coordinate measuring, geometrical feature, information representation modeling, surface model, tolerance item**

I. Introduction

In workpiece measuring, measuring information contains the surface category of inspected features, dimensions, tolerances, etc. Inspection information extraction has always been one of the important research contents of Computer-Aided Inspection Planning (CAIP) technology for years, in which measuring information is identified and extracted from the drawing or the model of a workpiece[1], [2]. The result of extraction becomes a data foundation for determining inspection tasks and planning inspection paths. Because of the complexity of measuring information constitutions, measuring information representation is necessary to recognize and extract measuring information.

Previous researches into measuring information representation and extraction were mostly based on the engineering descriptions as defined by traditional Computer-Aided Design (CAD) technology, 2D drawings or 2D drawings and 3D models. Model-Based Definition (MBD) technology and new-generation Geometrical Product Specifications (GPS) have proposed new realization approaches, technological environments and application requirements for workpiece measuring information representation and extraction, along with the universal application of digital measuring equipment.

MBD technology adopts a 3D entity model integrating various design and manufacturing information (including geometrical shape information, dimensions, tolerances, as well as process information, etc.), namely MBD dataset representation of products and components, to completely express product definition information in the 3D environment [3]-[5]. An MBD dataset also serves as the only Digital Product Definition (DPD) dataset in the process of a product life cycle [6]. MBD enables traditional CAD technology to evolve into the full-3D digital environment and stands for the state-of-the-art development stage and application trend in the CAD technology field.

As one of the most important technical standards in the manufacturing industry, new-generation GPS, based on metrological mathematics, is a new-type international standard system integrating geometrical product specifications and metrology verification. New-generation GPS covers a series of standards for dimensions, geometrical shape and tolerance, surface texture, and so on. New-generation GPS intends to bring design specifications, production and manufacturing, inspection and verification, and uncertainty evaluation throughout the entire product manufacturing process, act as a common criterion and a communication tool for product design, manufacturing, and measurement testing, and become a foundation and a bridge for integration of CAD, Computer-Aided Manufacturing (CAM), Computer-Aided Tolerancing (CAT), Computer-Aided Process Planning (CAPP),

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Computer-Aided Inspection Planning (CAIP), Computer-Aided Quality (CAQ), and other technologies [7], [8].

Currently, the measurement of dimensions, shapes, and locations are unified as coordinate measurement by digital measuring equipment such as Coordinate Measuring Machine (CMM) and Laser Tracker Measurement System (LT). The Coordinate measuring technology is playing a more and more important role in quality control of complicated structures and large size parts, and its scope of application is also popularized to common civil equipment manufacturing industries from key manufacturing sectors like aerospace and aviation, national defense, automobiles, and ships[9]. In this paper, according to coordinate measuring requirements and new-generation GPS, based on MBD datasets of workpieces, a theoretical representation model of measuring information, which defines measuring information constitution and the relationship between tolerance annotation and geometrical features in workpiece models, was established. Then a tool of measuring information extraction is developed based on the model.

II. TECHNOLOGICAL BACKGROUND

Based on traditional CAD definition technologies, some scholars developed a series of researches into recognition and extraction of measuring information of workpieces. They presented the relevance between tolerance information and geometrical features in the tolerance representation model, which offered beneficial references for research on the workpiece coordinate measuring information representation and extraction technology. 3D digital product definition technology based on MBD gives complete information representation of workpieces and data sources for measuring information extraction. New-generation GPS employs surface models as geometrical representation models while setting serial standards for geometrical accuracy design and verification, which realizes reclassification and definition of geometrical features of workpieces. Both of them try to obtain an unambiguous digital delivery vehicle among product design, manufacturing, and metrology verification. MBD dataset representation of workpieces and new-generation GPS offers the technology supporting environment for researches together in this paper.

A. Recognition and extraction of workpiece coordinate measuring information

The research on recognition and extraction of workpiece inspection information began with the research on the integration of CAD and CMM, mainly involving construction mode of the integration system and measuring path planning based on the extraction of inspection information. Hopp [10] first discussed how to extract tolerance items and measuring features from the 2D CAD database. Eversheim and Auge [11] established an integrated system connecting CAD with CMM to extract inspection information from CAD data via a connection program. EIMaraghy H and Gu [12] developed a Feature-Oriented Modeling and Planning System. Surface features, dimensions, and tolerances were captured by the part data file produced by the modeling system. Helmy [13] developed a feature recognition module that extracted the data from its B-Rep (Boundary Representation) model. Besides, literature [14], [15] constructed a CAIP system for CMM, in which extraction of inspection information was carried out. Afterward, Zhang *et al*. [16] brought up a method for establishing the relations between tolerance information and surface features. Vafaeesefat and EIMaraghy G [17] adopted the CAD model of workpiece and tolerance information as input to an algorithm for defining features accessibility. Limaiem and EIMaraghy H [18] identified inspection features from the CAD model and tolerances. Hwang *et al*. [19] proposed a method that allowed users to choose inspection features based on tolerance specifications.

Besides, Wang [20] set up an IGES(Initial Graphics Exchange Specification)-based CAD/CMM system that extracted CAD data of a workpiece and used the data to construct a model with measuring information. Using the combined representation of entity modeling, Wu [21] defined the feature models with CSG (Constructive Solid Geometry) and B-Rep by object-oriented technology and established relations among features. Out of 2D graphic neutral files (IGES files) of a workpiece, Ma [22] reconstructed its 3D model by extracting primitive information of geometrical features and constructed a workpiece measuring model by matching with tolerance information. In the Pro/E software environment, under geometrical construction history of a workpiece and its feature composition, Zhao *et al*. [23] established an inspection information model with tolerance information by capturing geometrical features and, in which the extracting objects were mainly simple geometrical features, such as extension and rotation. Ren [24] developed a STEP-based system of feature recognition to extract the data of 3D part models from STEP neutral files. By matching STEP with QDAS (Q-DAS manufacturing industry statistics analysis software data format standard) neutral files, Wang *et al*. [25] discussed how to recognize and deliver inspection information between CAD and CMM in the UG NX environment. Utilizing Open CASCADE, Liu *et al*. [26] developed a 3D display and edition environment based on neutral files (STEP and IGES files, etc.). A workpiece model constructed in the universal 3D CAD software was imported into this environment. Then geometrical features were extracted by manual click. How to extract tolerance information was not mentioned.

The ways to recognition and extraction of workpiece inspection information mentioned above are primarily based on workpiece model definition and representation technologies as furnished by traditional CAD technology. Workpieces were defined by 2D engineering drawings or 2D engineering drawings + 3D geometrical models, which do not adapt to the current development of digital design and manufacturing technologies. As for means of workpiece inspection information extraction, there are also problems, for instance, measuring information are defined in diversified ways, data are missing easily in communication and the process of information extraction is complicated, and so on. Additionally, under the mainstream trend of computer visualization processing of engineering problems, identifying and extracting measuring information via neutral files like IGES and STEP is less intuitive and convenient.

B. Workpiece measuring information representation modeling

Tolerance information and relevant geometrical feature information in a workpiece model are the main contents of the workpiece measuring information. Reasonably organizing and describing the relationship between tolerance information and geometrical features in a workpiece model facilitates the acquisition of the measuring information. Current relevant researches focus on tolerance information representation that serves as the foundation of tolerance analysis and tolerance synthesis.

Clement *et al*. [27] brought up TTRS (Technologically and topologically related surfaces)-based tolerance representation model. Surface features extracted from the workpiece CAD model are organized with a binary tree. According to the datum elements of the surface features and their relations defined by the TTRS model, tolerance information of the surface features was determined and was associated with the corresponding datum elements. Based on the TTRS representation model, Liu *et al*. [28] put forward a feature-based hierarchical representation model of tolerance information. By constructing the feature-based TTRS (FTTRS), minimum feature datum elements, and constraint primitives, the framework of the hierarchical representation model was formed. And then the tolerance information was combined with the framework in turn according to tolerance syntax. Based on the two above mentioned, literature [29]-[31] further improved relevant research by polychromatic sets theory.

In earlier research[32], the author established a measuring information representation model based on the MBD dataset of workpieces, in which tolerance, geometrical features, and model datum/coordinate system were used as constituents of measuring information and relationship of the measuring information were defined. Referring to the concept of TTRS, the new-generation GPS used the surface model to represent basic geometrical features. In this paper, a measuring information representation model was constructed based on MBD datasets and new-generation GPS, in which the measuring features can be represented and classified by invariance classes of the surface model. The representation approach of measuring information is more clear and concise than the earlier model.

C. MBD dataset representation of a workpiece model

Model-based Definition is a way of fully describing the detailed product information, in which 3D GD&T(Geometric Dimensioning and Tolerancing), as well as notes, are stored in the 3D model and various design and manufacturing files are used as supplementary. The 3D model with complete product information is regarded as the sole source for manufacturing. Borrowing the experience and relevant standard system of Boeing in full-3D digital product definition, as support for MBD technology, the American Society of Mechanical Engineers (ASME) released “digital product definition data practices (ASME Y14.41-2003)” in 2003 [6], [33]. Subsequently, the general 3D CAD software, such as CATIA, UG NX and Creo, started supporting that standard, to provide MBD technical support and modeling environment. International organizations and countries concerned, including ISO and China, also formulated standards or specifications of their own on digital product definition [33]-[35].

An MBD dataset of a workpiece contains the exact solid, its associated 3D geometry, 3D annotations of the workpiece’s dimensions and tolerances, and process information [6]. An MBD dataset of a workpiece model supplies the data source and data foundation for downstream manufacturing work like processing, assembly, measuring, and detection. And model-based planning, verifying, and implementing can be carried out [36], [37]. Fig.1 shows a workpiece’s MBD dataset incorporating complete information of design and manufacturing, which was modeled in the environment of UG NX.

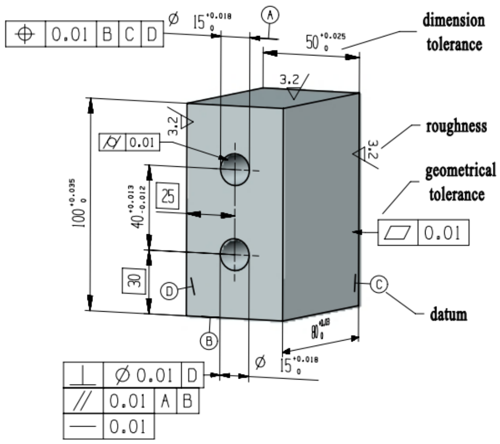


Fig. 1 MBD Dataset of a workpiece in UG NX

According to the technical specifications of MBD, in the model-cored workpiece definition, the MBD model of workpiece consists of a design model, explanatory notes and attributes, as shown in Fig. 2.

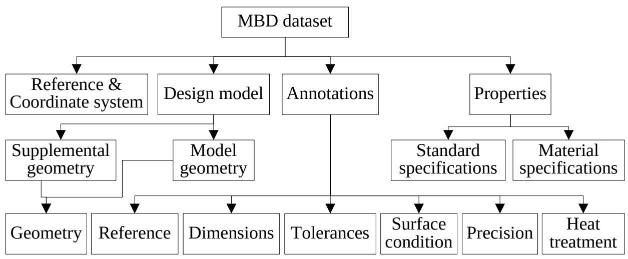


Fig. 2 Information constitution of MBD Dataset

In Fig. 1 and Fig. 2, the design model describes geometrical information of the workpiece, which expresses the design intention that includes design datum and the exact solid, reference model, constraints, etc. The explanatory notes, which include dimensions, tolerances, annotations, text, symbols, manufacturing process, accuracy, and other contents, were defined in specific annotation planes. The notes are required for workpiece processing and related to corresponding geometrical elements in the entity model. The properties include materials, heat treatment, and other information about manufacturing and testing [38]. Therein, what is the most important in technical specifications of MBD is that such specifications specified the annotation rules of product dimensions and tolerances and the expression methods of process information in 3D entity model, and represented the corresponding relationship among dimensions, tolerance information, and geometrical features, which thus laid a vital foundation for acquiring measuring information and other process information.

Currently, MBD technology has been applied in the aviation industry (typically Boeing and Airbus), and mainly applied to digital product definition and digital information delivery in the manufacturing process. In combination with all kinds of digital measuring equipment, some companies have started setting up MBD-based digital measuring and verification systems. Along with the formation and promulgation of new-generation GPS, the blending and integration of MBD and new-generation GPS have become a trend.

D. New-generation GPS standard system and its geometrical representation model

New-generation GPS realizes the unification of function, design and verification specifications of products employing parameterized geometry and metrological mathematics. It adopts a uniform basic geometrical representation model, namely the surface model, to realize the representation of GPS at respective stages. Serial standards cover all technical specifications concerning dimensional tolerance, geometrical tolerance, and surface texture and guide the entire product quality control process of the design, manufacturing, measurement, and inspection of products [39].

Constitution of new-generation GPS standard system

New-generation GPS consists of dimensional tolerance, geometrical tolerance and surface texture tolerance. Therein, geometrical tolerance is divided into form tolerance, orientation tolerance, position tolerance, and run-out tolerance, as shown in Fig. 3. All types of tolerance, which are closely related to product design, are the composition of tolerance contents of measuring information extracted from the MBD model of a workpiece [40].

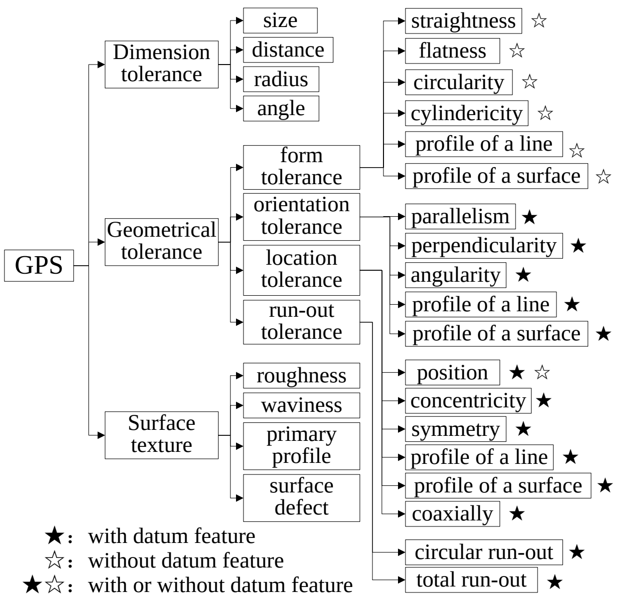


Fig. 3 New-generation GPS standard system

Surface Model and its geometrical features

The surface model is one of the key theories introduced in new-generation GPS and is used to realize the unification of geometrical products specification in respective stages like function, design, manufacturing, measurement, and inspection. Depending on different stages, the surface model is divided into the nominal surface model, the normative surface model, and the verified surface model [41], [42], as shown in Fig.4. Regarding tolerance and geometrical information extraction based on the MBD dataset, the focus lies in the nominal surface model that integrates dimensions, tolerance and other explanatory notes.

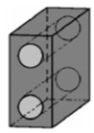
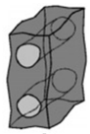
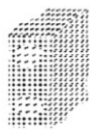
surface model	nominal surface model	specification surface model	real surface model	specification surface model
legend	 (a)	 (b)	 (c)	 (d)
GPS stage	specification designation		production	verification

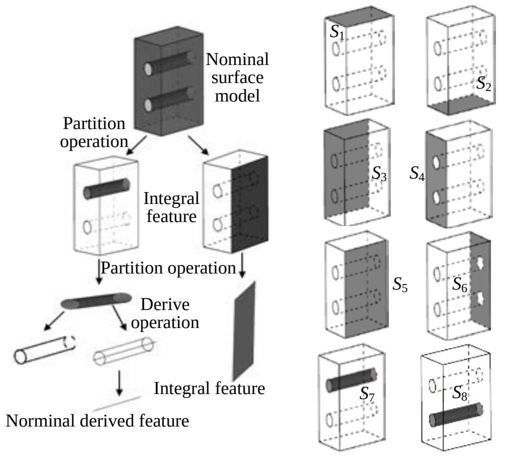
Fig. 4 The surface model of new-generation GPS

Based on the surface model, new-generation GPS reclassifies and redefines geometrical features. Geometrical features, which are the planes, lines, and points that constitute geometrical surfaces of a workpiece, play a vital role in the specification, processing, and verification of products [41], [42]. For the requirements of the workpiece function description, geometrical features are divided into integral features and derived features. The integral features are the lines or planes belonging to the surface model of the workpiece whereas the derived features are the center point, median line, median surface or offset plane defined from integral features. The integral and derived features of the surface model are illustrated in Fig. 5. Usually, in the MBD-based workpiece model, various types of tolerance information are annotated on integral features of the geometrical model or done on derived features and eventually related to the integral features. The surface model of new-generation GPS corresponds to the B-rep data structure of the geometrical model established in the universal CAD system, which embodies the consistency of GPS standard system and MBD-based CAD technology in geometrical model representation and facilitates extraction of tolerance information and relevant geometrical information in 3D CAD environment.

The workpiece model as shown in Fig. 1 is a surface model whose integral features contain planes and cylindrical surfaces illustrated in Fig. 5. Fig. 5(a) shows the separation operation of the surface model and Fig. 5(b) does 8 surface integral features $S_1 \sim S_8$ that constitute the surface model, which includes six plane surfaces and two cylindrical surfaces.

Constitution of surface features based on invariance classes

According to the concept of invariance degree, new-generation GPS defines ideal features of the surface model as 7 invariance classes, as shown in Table I. Location and orientation of an ideal feature is defined by its situation feature, as well as relative location and orientation between two ideal features is defined by the situation characteristic. Based on the surface model and the invariance classes defined in new-generation GPS, the geometrical features related to tolerance items in MBD datasets can be classified into correspondent invariance class, which lays the foundation for inspection planning.



(a) Separation operation (b) Integral features

Fig. 5 The integral features and derived features of a nominal surface model

III. MBD- and GPS-based Measuring Information Constitution and Representation Modeling

The MBD dataset of a workpiece presents the basic data source of measuring information extraction.

According to tolerance classification, surface model, and geometrical features in new-generation GPS, the measuring information representation model, which defines the measurement feature constitution and the relationship among those measuring features in the MBD dataset of a workpiece, is constructed. The model can instruct the extraction of measuring information.

A. Definition of measuring information constituent in an MBD dataset

Dimensions and tolerances annotated on the MBD model of a workpiece are an important basis for the determination of measuring features in the workpiece coordinate measuring. Currently, mainstream 3D CAD software systems can support the technical specifications of MBD. Using CSG (Constructive Solid Geometry) and B-rep (Boundary representation) mixed data structure, the CAD system records the modeling history, the topology, geometrical information, and the relevance between 3D annotations and geometrical features in a workpiece model. Thus, for a workpiece MBD model, if 3D annotation items are randomly selected, it is possible to query geometrical information relevant to them. On the contrary, if geometrical features are randomly selected, it is possible to query all annotation information relevant thereto. In coordinate measuring of a workpiece, measuring objects are geometrical surfaces with tolerance demands. Accordingly, in combination with related contents in new-generation GPS, through recognizing tolerance items, geometrical features associated with them were extracted to determine the constituent set of the workpiece measuring information.

Therefore, the workpiece measuring information constituent set consists of Tolerance Set (*TS*), Feature Set (*FS*) and Model Datum & Coordinate (*MDC*), i.e.

$$E = \{TS, FS, MDC\} \tag{1}$$

Therein, Tolerance Set (*TS*) is composed of corresponding tolerance subsets, Feature Set (*FS*) is made up of integral features of workpiece surface models, and Model Datum & Coordinate (*MDC*) offers the overall positioning datum and coordinates of a workpiece model and its respective geometrical features.

Tolerance Set(TS)

According to new-generation GPS, Tolerance Set (*TS*) consists of corresponding Tolerance Set of Dimension (TS_D), Tolerance Set of Geometry (TS_G) and Tolerance Set of Surface Texture (TS_{ST}), i.e.

$$TS = \{TS_D, TS_G, TS_{ST}\} \tag{2}$$

Concerning constituent subsets of *TS*, TS_D and TS_{ST} are not further divided into subsets due to few types at the lower level. The existence of major subordinate categories in TS_G leads to further division into subsets.

TS_D consists of all dimensional tolerance objects in a workpiece MBD dataset.

$$TS_D = \{T_{d1}, T_{d2}, \cdots, T_{dm_d}\} \tag{3}$$

Pursuant to GPS standard system, TS_G is composed of Tolerance Set of Geometrical Form (TS_{GF}), Tolerance Set of Geometrical Orientation (TS_{GO}), Tolerance Set of Geometrical Location (TS_{GL}) and Tolerance Set of Geometrical Run-out (TS_{GR}), i.e.

$$TS_G = \{TS_{GF}, TS_{GO}, TS_{GL}, TS_{GR}\} \tag{4}$$

TS_{GF}, TS_{GO}, TS_{GL} and, TS_{GR} in TS_G are made up of corresponding tolerance objects.

TABLE I
INVARIANCE CLASS

Invariance class	Invariance degree
Complex surface	None
Prismatic surface	Translation along a straight line(one direction)
Surface of revolution	Rotating round a straight line(one direction)
Helical surface	Translation along a straight line(one direction) &rotating round a straight line(one direction)
Cylindrical surface	Translation along a straight line(one direction) &rotating round a straight line(one direction)
Plane	Rotating round a straight line(one direction) &translation on the plane perpendicular to the line(two directions)
Spherical surface	Rotating round one point(three directions)

$$TS_{GF}=\{T_{gf1},T_{gf2},\cdots,T_{gfm_f}\} \tag{5}$$

$$TS_{GO}=\{T_{go1},T_{go2},\cdots,T_{gom_o}\} \tag{6}$$

$$TS_{GL}=\{T_{gl1},T_{gl2},\cdots,T_{glm_l}\} \tag{7}$$

$$TS_{GR}=\{T_{gr1},T_{gr2},\cdots,T_{grm_r}\} \tag{8}$$

Similarly, so is TS_{ST}.

$$TS_{ST}=\{T_{st1},T_{st2},\cdots,T_{stm_{st}}\} \tag{9}$$

In different tolerance sets and subsets, specific tolerance objects extracted eventually are classified into tolerance items depending on attributes. For instance, attributes of dimensional tolerance object, like linear dimensions, distance, radius, and angle, determine the tolerance type of corresponding extracted object. Meanwhile, the number of tolerance objects in the tolerance subsets is subject to tolerance annotations of the workpiece model, either null or covering all tolerance types.

Feature Set (FS)

New-generation GPS adopts surface model as the basic geometrical representation model and defines the ideal features of surface models as 7 invariance classes. Currently, in an MBD dataset, various types of tolerance information are indicated on integral features of the geometrical model or done on derived features and eventually related to integral features.

Therefore, Feature set (FS) consists of surface subsets of 7 invariance classes, which constitute the surface model of a workpiece. Subject to complexity of different surfaces, there are Feature Set of Plane (FS_P), Feature Set of Cylindrical Surface (FS_C), Feature Set of Spherical Surface (FS_S), Feature Set of Prismatic Surface (FS_T), Feature Set of Surface of Revolution (FS_R), Feature Set of Helical Surface (FS_H) and Feature Set of Complex Surface (FS_X) in sequence. In general, the first six kinds of surfaces are common and other model surfaces may be included in the FS_X. FS may define as

$$\begin{aligned}FS&=\{FS_P,FS_C,FS_S,FS_T,FS_R,FS_H,FS_X\}\\&=\left\{S_1,S_2,\cdots,S_n\right\}\end{aligned} \tag{10}$$

Therein, $\left\{S_1,S_2,\cdots,S_n\right\}$ is a set of geometrical features related to tolerance annotations on surface models of a workpiece. The set includes either all or part of integral features of surface models. According to 7 invariance classes, FS consists of surface subsets containing the respective surface features, which are as follows:

$$FS_P=\{S_{p1},S_{p2},\cdots,S_{pn_p}\} \tag{11}$$

$$FS_C=\{S_{c1},S_{c2},\cdots,S_{cn_c}\} \tag{12}$$

$$FS_S=\{S_{s1},S_{s2},\cdots,S_{sn_s}\} \tag{13}$$

$$FS_T=\{S_{t1},S_{t2},\cdots,S_{tn_t}\} \tag{14}$$

$$FS_R=\{S_{r1},S_{r2},\cdots,S_{rn_r}\} \tag{15}$$

$$FS_H=\{S_{h1},S_{h2},\cdots,S_{hn_h}\} \tag{16}$$

$$FS_X=\{S_{x1},S_{x2},\cdots,S_{xn_x}\} \tag{17}$$

In "(11)" to "(17)", $(n_p+n_c+n_s+n_t+n_r+n_h+n_x)=n$.

Coordinate measuring needs detailed geometrical information of the above geometrical features of FS and its subsets, like datum point, normal vector, profile dimensions, etc. In a universal 3D CAD software environment supporting MBD modeling, the detailed geometrical information can be extracted by customizing data access interface or other technical means.

B. Definition of the relationship among measuring information constituents

Based on the definition of measuring information constituents above-mentioned, due to different tolerance items relevant to different geometrical features, geometrical features relevant to TS_D are defined as

$$F^{TD}=\{F_1^{TD},F_2^{TD},\cdots,F_i^{TD}\} \tag{18}$$

Those relevant to TS_{GF}, TS_{GO}, TS_{GL}, and TS_{GR} in TS_G as

$$F^{TGF}=\{F_1^{TGF},F_2^{TGF},\cdots,F_{j_f}^{TGF}\} \tag{19}$$

$$F^{TGO}=\{F_1^{TGO},F_2^{TGO},\cdots,F_{j_o}^{TGO}\} \tag{20}$$

$$F^{TGL}=\{F_1^{TGL},F_2^{TGL},\cdots,F_{j_l}^{TGL}\} \tag{21}$$

$$F^{TGR}=\{F_1^{TGR},F_2^{TGR},\cdots,F_{j_r}^{TGR}\} \tag{22}$$

And those relevant to TS_{ST} as

$$F^{TST}=\{F_1^{TST},F_2^{TST},\cdots,F_k^{TST}\} \tag{23}$$

Then inspection information Set (IS) determined by tolerance annotations consists of TS_D, TS_G, TS_{ST} and their dependent geometrical features, and the formula is as follows:

$$\begin{aligned}IS=\big\{&(TS_D\cup F^{TD}),(TS_{GF}\cup F^{TGF}),(TS_{GO}\cup F^{TGO}),\\&(TS_{GL}\cup F^{TGL}),(TS_{GR}\cup F^{TGR}),(TS_{ST}\cup F^{TST})\big\}\end{aligned} \tag{24}$$

C. A workpiece measuring information representation model

Following the MBD dataset of a workpiece, based on the tolerance classification and invariance class division of surface geometrical features in new-generation GPS standard system, a workpiece measuring information representation model, which defines measuring information constituents and their relationships, is constructed by referring to tolerance representation model, as shown in Fig. 6.

In Fig.6, Model Datum and Coordinate (*MDC*) offer the overall location datum and coordinates of all geometrical features of the workpiece model as a data foundation of workpiece coordinate measuring datum. *TS* is the basis for determining inspection tasks. Respective tolerance objects of T_{SD}, T_{SG}, and TS_{ST} are relevant to different surface geometrical features of the workpiece model. And corresponding surface geometrical feature sets are included in *FS* by dint of subsets of *FS*. Besides, surface texture tolerance in TS_{ST}, which must be measured by special tools, is not involved in coordinate measuring.

IV. Extraction of Measuring Information Based on Representation Information

Measuring feature composition and their relationship of a workpiece model is defined in the measuring information representation model, which provides a foundation for extracting coordinate measuring information.

A. The process of measuring information recognition and extraction

Tolerance annotation information in the MBD dataset of a workpiece gives the accuracy target of geometrical features and is an important basis for judging measurement features in coordinate measuring. Therefore, according to the principle of determining measurement features with dimensional tolerance and geometrical tolerance, the process of measuring information recognition and extraction is shown in Fig. 7.

Tolerance items are first recognized. And the geometrical features are extracted based on the tolerance items. Some tolerance objects are annotated on integral features, for example, linear size tolerance annotated on two planes. Some tolerance objects are annotated on derived features, for example, distance tolerance annotated on axes of two cylinders. For tolerance items annotated on integral features, integral features are extracted based on tolerance items. For tolerance items annotated on derives features, derived features are extracted based on tolerance items, and then integral features are extracted by related derived features. Finally, the extracted features are categorized by invariance class, which will serve as the basis for inspection planning.

B. Extraction of tolerance information and relevant geometrical features

In the UG NX customizing development toolkit, NX Open API provides the access functions for acquiring various tolerance items and related geometrical features. A tool for measuring information extraction is developed using the UG NX customizing development toolkit. The detailed process of extracting tolerance information and relevant geometrical features is described below:

Firstly, tolerance items are selected with the class selection dialog generated by calling UF_UI_select_with_class_dialog.

Secondly, dimensions tolerance features selected are inquired with UF_GDT_ask_size_tolerance_parms and geometrical tolerance features selected are inquired with UF_GDT_ask_fcf_parms.

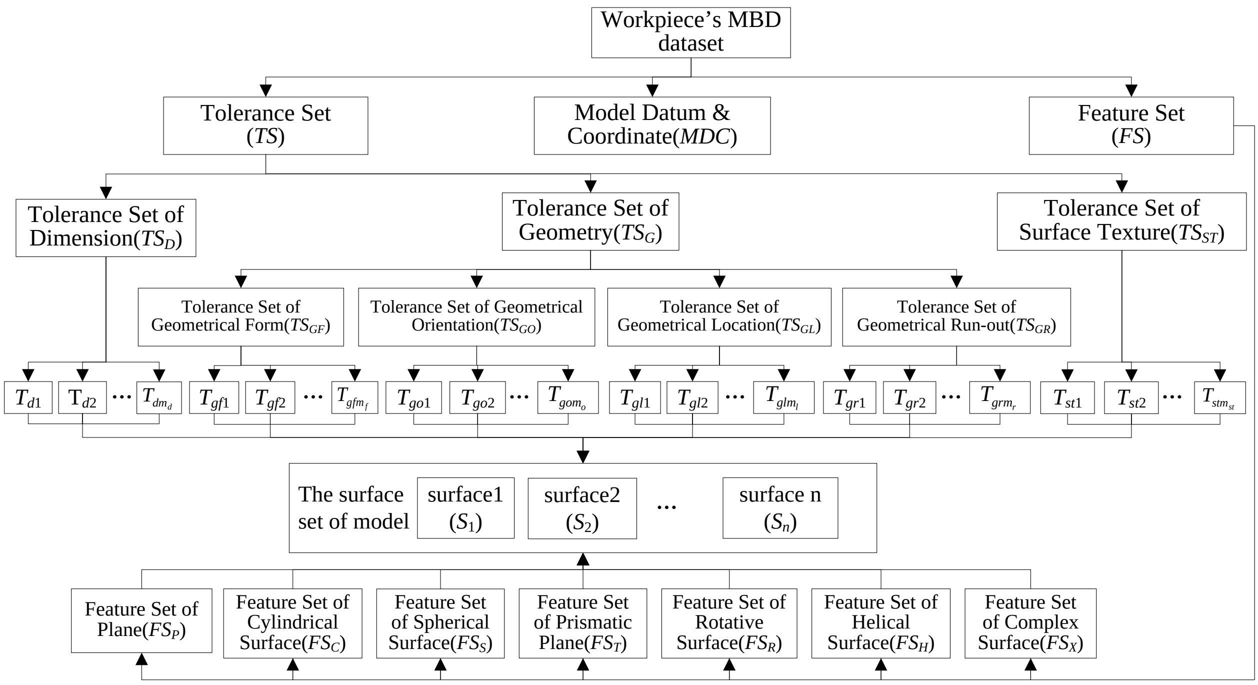


Fig. 6 Workpiece measuring information representation model

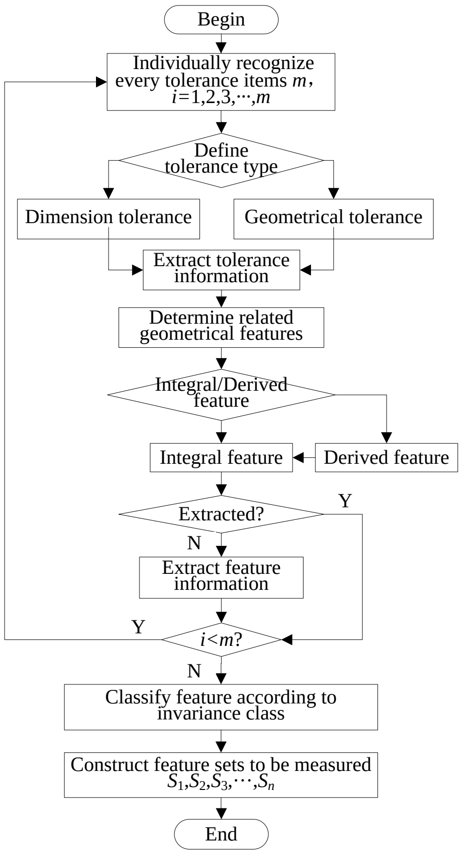


Fig. 7 The process of measuring information recognition and extraction

Thirdly, for a tolerance object, its type is firstly inquired. In NX Open API, the tolerance type is defined by an enumerated type variable, UF_GDT_size_value_type_e for dimension tolerance and UF_GDT_characteristic_e for geometrical tolerance. Then, according to the tolerance type, detailed tolerance information is obtained. Dimension tolerance information contains the nominal value, upper tolerance value, lower tolerance value, etc. Geometrical tolerance information contained the tolerance zone, datum, etc.

Fourthly, the identifiers of geometrical features related to tolerance objects are gotten with a function named NXOpen::Annotations::PmiLabel::GetAssociatedObject. Then the detailed information, which includes type, size, center point, normal direction, and the boundary, is extracted with functions like UF_MODL_ask_face_edges, UF_EVAL_ask_arc, etc.

The tool for measuring information extraction is shown in Fig. 8, in which taking an MBD dataset of a flange as an example, the measuring information is extracted. When selecting tolerance items and clicking the buttons, the detailed information of tolerance items and associated features is extracted and listed on the interface. Measuring information can be saved in a specific database for inspection planning.

Results of measuring information extraction show the detailed composition of measuring features that are the data source for inspection planning. Using the detailed measuring information, the geometrical features' sampling plan, probe directions, and probe path can be determined.

V. Discussion and Conclusion

Recognition and extraction of measuring information have been a vital component of Computer-Aided Inspection Planning technology and become the foundation for workpiece coordinate measuring. The promulgation of new-generation GPS pays more attention to coordination with coordinate measuring technology than before. MBD dataset representation of a workpiece offers a complete measuring information extraction environment for workpiece coordinate measuring. Therefore, the integration of new-generation GPS and the MBD method provides measuring information description and representation with the technological application environment different from before.

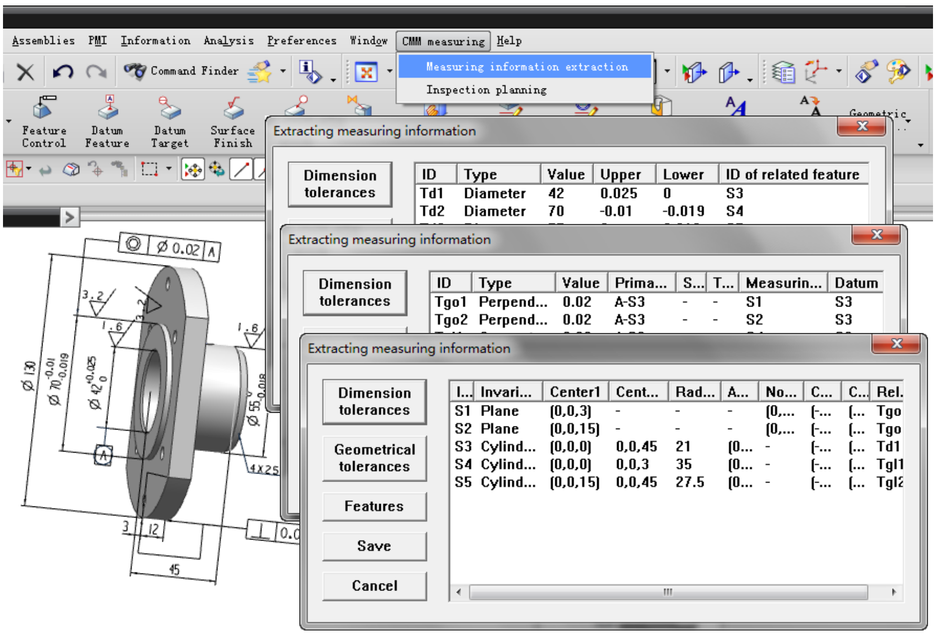


Fig. 8 Extraction of dimension tolerance, geometrical tolerance, and related features

Based on new-generation GPS and the MBD method, this paper mainly develops the following work :

(1) The composition of workpiece measuring information is defined based on the dominant thought that tolerance annotations are the main basis for determining measuring features. And tolerance items of the MBD dataset are used as the primary constituent of the measuring information.

(2) The relationship between tolerance annotations and geometrical features is defined following the concept of the surface model, integral feature, derived feature, and invariance class.

(3) A measuring information representation model is established based on measuring information constituents and their relationship.

(4) The method of extracting features through tolerance annotation information is proposed and a tool of measuring information extraction is developed.

Extracting measuring features through tolerance annotation eliminates numerous non-coordinate-measuring geometrical features technically. Meanwhile, what needs attention is that in new-generation GPS, some invariance classes, like revolutions, helicoids, and composite surface, involve more subsets of complex surface features. Thus, the definition and classification of geometrical features need to be further improved while the extraction of measuring information needs to be more deeply researched in follow-up work.

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