Categorical data modelling for Cylindricity Consistent with Geometrical Product Specifications Standard System

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ABSTRACT

Geometrical Product Specifications and Verification (Abbreviated as GPS) is an international standard system regarding standardization of dimensional, tolerancing, surface texture and related metrological principles and practices in the charge of Technical Committee ISO/TC213. Integrated information system is necessary to encapsulate the knowledge in GPS to extend the application of GPS in digital manufacturing. Establishing a data structure that is suitable for GPS data is one of the main works in building the integrated information system. This paper focuses on cylindricity and the main points of the paper are as follows: proposed the complete verification operator and the complete drawing indication for cylindricity based on GPS; models the inter/intra relationships between the elements of operations within cylindricity operator based on category theory; integrates the categorical data model of each operation within cylindricity into the categorical data model for cylindricity and solved the storage format and closure of query for the categorical data model by the pull-back structure and functor transform in category theory respectively.

Keywords: GPS, cylindricity, categorical data modelling, pull back, functor

1. INTRODUCTION

Geometrical Product Specifications (GPS) is an international standard system regarding standardization of dimensional, tolerancing, surface texture and related metrological principles and practices in the charge of Technical Committee ISO/TC213 established in 1996[1]. The motivation of the establishment of ISO/TC 213 and GPS standard system is to make the standardization of geometrical tolerances and surface texture suitable for the information age[2], and to integrate specifications and verification of geometrical characteristics to make their specifications more unambiguous and unique, further to reduce uncertainties and cost in product life cycle. In order to reach the above aim, and to harmonize with the digitization for manufacturing industry, the GPS standard system is mathematics based and many new algorithms and concepts, such as partition, extraction, filtration, association, have been utilized in GPS [3]. Besides, these concepts are intricately related, which makes them inconvenient to be used directly. Therefore, it is of practical meaning to build an integrated system to encapsulate the information in GPS. A global data model which is able to properly represent and store all the elements and their relationships involved in the integrated information system for the downstream analysis, is the key problem to be solved. For a complicated component, it consists of decades of parts, a part consists of several to dozens of geometrical features, and a geometrical feature is defined by a couple of geometrical specifications. Thousands of tables will be used if all the entities and their relationships are represented by tables in the relational model, also the conjunction, a fairly inefficient operation, will be used frequently. In addition, the tables in the relational model cannot represent the relationships in cylindricity clearly. Y Wang[4] analyzed the disadvantages of the relational model and object-oriented modelling and compared them with the data modelling based on category theory[5] (named as Categorical data modelling). She used the categorical data model to represent and store the knowledge in surface texture successfully. Up to present, no publications were found to investigate data modelling for cylindricity in the framework of GPS. This paper presents the categorical data modelling for integration between specifications and verification for cylindricity consistent with GPS standard system.

2. CATEGORICAL DATA MODELING FOR CYLINDRICITY

A specification is a set of conditions on a characteristic defined from geometric features which are created from the model of the non-ideal surface of the part (skin model) by different operations [6]. In order to integrate specification and verification, and thus to reduce various uncertainties in different stages in the product life cycle, normally the complete style for the drawing indication for cylindricity should be '**Characteristic** + **Conditions**', which is shown in figure 1. It is a complement to ISO 1101:2004.

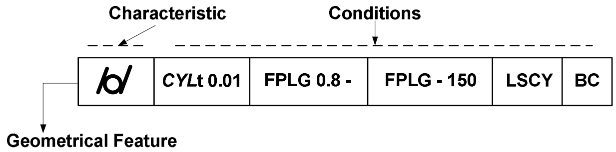

Figure 1 The drawing indication for cylindricity consistent with GPS

Where, '*CYL*t' is the parameter and '0.01' is the limited value for evaluation of cylindricity; 'FPLG' is the linear profile Gaussian filter which is used to obtain the cylindrical feature; '0.8'/ '150' are the nested indexes of the filter in generatrix and radial section respectively; 'LSCY' means that the least square association method is used to obtain the reference cylinder; 'BC' means that bird cage sampling strategy is used. Most of these symbols are published in reference [8].

Considering the advantage of categorical data modelling stated in ref[4], we utilize it to model the integration between specifications and verification for cylindricity consistent with GPS. In terms of the requirements of GPS, the evaluation of cylindricity should follow the procedure "Partition→Association→Evaluation" [7]. Based on the specification operator and combine it with the practical measurement procedure, the actual verification operator for cylindricity should be "Partition→Extraction→Filtration→Association→(Parameter)→Evaluation". Each operation is regarded as a **CATEGORY**. We take Partition and Filtration as examples to illustrate the modelling.

2.1 Partition

Partition is a feature operation used to identify bounded features. After the analysis of the inherent characteristics of cylindrical feature, we know that a cylinder has an intrinsic characteristic, the diameter of radial section, marked Ref_diameter, and it has another geometry parameter, the length of generatrix, marked as Length_G. According to ISO/TS 17450-1[17], any geometrical feature belongs to an invariant type, marked as feat_type. In addition, any type of geometrical feature has it own degree of freedom (DOF). Based on the above analysis, we can get the categorical data model of partition for cylindricity as shown in figure 2.

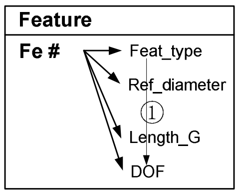

Figure2 The categorical data model of **Partition** for cylindrical feature

Where, rectangles represent category; the first line above represents the name of the category; the elements below the category name are the objects of the category; the initial internal object stores a unique system automatically generating identifier value; and all the different morphisms are represented by various arrows (the same below). Fe# is the initial object for category **Feature**, and it is generated by the system automatically; 'arrow ①' means *From the analysis of geometrical features, it was classified into seven types, and each geometrical feature belongs to one of the seven types. Hence, DOF is determined by the type of geometrical feature*.

2.2 Filtration

Filtration is an operation used to remove the unwanted information and obtain the wanted information from the measured data. The filters used to obtain the appropriate profile in radial and axial directions from cylindrical feature are selected from ISO/TS16610-series standards according to their functions. The nested index for filter in each direction is cutoff frequency (f_C) and cutoff wavelength (λ_C) respectively. Since there is no international standard for their default value, they have to be indicated in the drawing indication.

There are two styles for applications of filters in both radial and axial directions, as shown from Figures 3 to Figure 6. One type is a single long-pass filter and the other is the set of a long-pass filter and a short-pass filter. When a long-pass filter is used, the upper limit of its nested index for axial section is ∞ mm, and the lower limit of its nested index for radial section is 1UPR. When a short-pass filter is used, it must be the application of the set of a long-pass filter and a short-pass filter, so the long-pass filter should also be indicated.

Filter_name Cutoff wavelength_Long pass - ∞

Figure 3 Style of using single long-pass filter for axial section

Filter_name 1UPR - Cutoff frequency_Long pass

Figure 4 Style of using single long-pass filter for radial section

Filter_name Cutoff wavelength_short pass - Cutoff wavelength_long pass

Figure 5 Combination of a long-pass filter and a short-pass filter for axial section

Filter_name Cutoff frequency_short pass - Cutoff frequency_long pass

Figure6 Combination of a long-pass filter and a short-pass filter for radial section

In practical application in industry, nested indexes such as cutoff wavelengths (cutoff wavelength for short pass filter and long pass filter are marked as Lower-wavelength and Upper_wavelength respectively) and cutoff frequencies for filters (cutoff frequency for short pass filter and long pass filter are marked as Lowlimt_frequency and Uplimit_frequency respectively) are selected from table 1and table 2 for convenient comparison of results.

Table 1 Cutoff wavelength λ_C series (mm)

···	0.008	0.025	0.08	0.25	0.8	2.5	8	···

Table 2 Cutoff frequency series(UPR)

···	15	50	150	500	1500	···

If the designers cannot decide which one is suitable for their situation, they can also select cutoff wavelength from table 3, according to the *Length_G* of cylindrical feature, and cutoff frequency from table 4 according to the *Ref_diameter*.

Table 3 λ_C configured according to *Length_G*

Length_G (*mm*)	λ_C (*mm*)
Length_G ≤ 240	0.8
240 < *Length_G* ≤ 750	2.5
Length_G > 750	8

Table 4 f_C configured according to *Ref_diameter*

Ref_diameter **(*mm*)**	f_C **(UPR)**
Ref_diameter ≤ 8	15
8 < *Ref_diameter* ≤ 25	50
Ref_diameter > 25	150

Based on the analysis for filtration for cylindrical feature, its categorical data model was represented as figure 7.

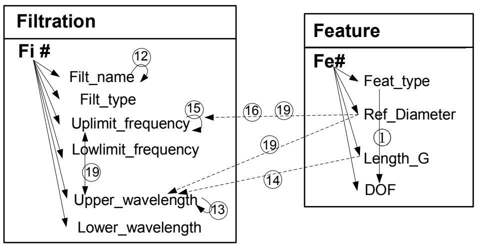

Figure7 The categorical data model for filtration for cylindricity (including the relationships in category **Partition**)

Where, Fi is the initial object for category **Filtration**. ⑫: Filters will be selected from 16610-series according to their functions. ⑬: λ_C was set by designers according to actual situation. Normally, λ_C will be selected from series number in table 1 in convenient for comparison. ⑭: If the designers cannot distinguish the series values of λ_C listed in table 1, then they can also select it from table 3 according to *Length_G*. ⑮: f_C was set by designers according to actual situation. Normally, f_C will be selected from series number in table 2 in convenient for comparison. ⑯: If the designers cannot distinguish the series values of f_C listed in table 2, they can also select it from table 4 according to *Ref_diameter*. ⑲: The cutoff frequency f_C , the cutoff wavelength λ_C , and the nominal diameter should satisfy the relationship presented as $f_C = \frac{\pi \times Ref\_diameter}{\lambda_C}$.

2.3 The refinement mechanism in categorical data model for cylindricity

The arrow can represent the relationships between objects briefly. However, the detailed meaning of the relationships can not be represented clearly. In categorical data modelling, the arrow that represents the relationship between two objects in different categories can be refined by the pull back structure in category theory. Thereby, for the drawing indication for cylindricity consistent with geometrical product specifications shown in figure 1, it is the relationships among the objects in the Categories **Restriction, Parameter, Association, Filtration** and **Sampling**, which was represented and refined by a pull back structure p1, as shown in figure 8.

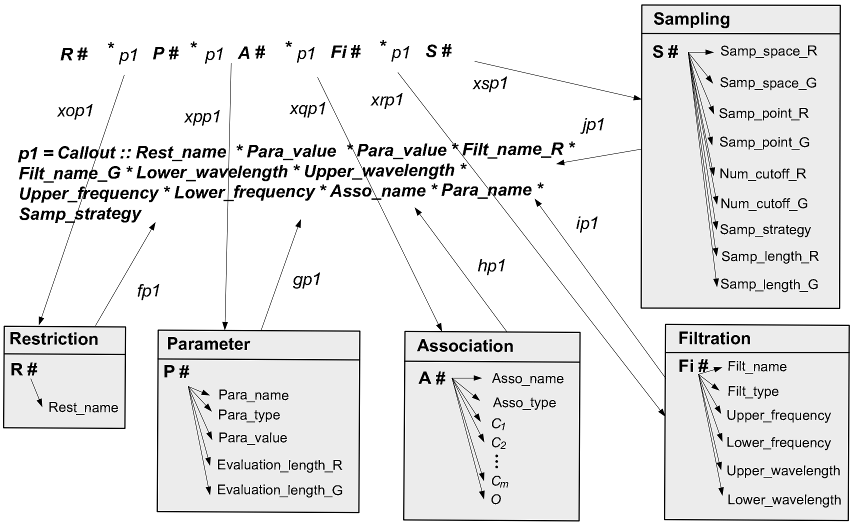

Figure 8 The drawing indication for cylindricity is represented by pull back p1

In Category $\boldsymbol{Cat_{p1}}$, Ob_{p1}={($R\#*_{p1}P\#*_{p1}A\#*_{p1}S\#*_{p1}Fi\#$),*R#*,*P#*,*A#*,*S#*,*Fi#*,*Rest_name*, *Para_value*,*Filt_name _R*, *Filt_name_G*, *lower_wavelength*,*Upper_wavelength*,*Upper_frequency*,*Lower_frequency,Asso_name*, *Para_name*, *Sampling_strategy*}; Mor_{p1}={*xop1*: ($R\#*_{p1}P\#*_{p1}A\#*_{p1}S\# *_{p1}Fi\#$)→ *R#*, *xpp1*: ($R\#*_{p1}P\#*_{p1}A\#*_{p1}S\#*_{p1}Fi\#$) →*P#*, *xqp1*: ($R\#*_{p1}P\#*_{p1}A\#*_{p1}S\#*_{p1}Fi\#$) →*A#*, *xrp1*: ($R\#*_{p1}P\#*_{p1}A\#*_{p1}S\#*_{p1}Fi\#$) →*Fi#*, *xsp1*: ($R\#*_{p1}P\#*_{p1}A\#*_{p1}S\#*_{p1}Fi\#$) → *S#*, hom(*P#*,*Para_value*): *P#→Para_value*, hom(*Fi#*,*Filt_name_R*): *Fi#→ Filt_name_R*, hom(*Fi#*,*Filt_name_G*): *Fi#→Filt_name_G*, hom(*Fi#*,*Cutoff_wavelength*): *Fi#→ Cutoff_wavelength*, hom(*Fi#*,*Upper_frequency*): *Fi#→ Upper_frequency*, hom(*A#*,*Asso_name*): *A#→ Asso_name*, hom(*P#*, *Para_name*): *P#→Para_name*, hom(*S#*,*Sampling_strategy*): *S#→Sampling_strategy*, hom(*R#*,*Rest_name*): *R#→Rest_name*, hom(*Fi#*,*Upper_wavelength*): *Fi#→ Upper_wavelength*, hom(*Fi#*,*Lower_ frequency*): *Fi#→ Lower_frequency*}.

2.4 Manipulation and case study for the categorical data model

The categorical data model uses categories, objects, morphisms(arrows) and pull back structures to represent, refine and store the entities and the relationships between entities. However, how to realize the query in the integrated information system? And in addition, how to keep the closure for query? The categorical data model uses its functor transform to realize it, which is the forgetful functor.

For example, *Please output the elements of a drawing indication for a cylindricity, in which the specified value of cylindricity = '0.007 mm' and the parameter=* '*CYL*t'.

This query will access the categories such as **Restriction**, **Parameter**, **Association**, **Filtration**, **sampling** and the **pull back** categories **p24**, **p26**, **p34**, **p43** and **p44**. It is a complex process. The manipulation for this process is as follows:

Firstly, the system can derive a category ***A*** from the category Parameter, where ***A*** is a subcategory of the category **Parameter**;

Secondly, the system can derive the instant category ***K*** after a set of intermediate steps and get the pull back category **p1** from a general functor transform;

Finally, the system can derive the subcategory of category ***K***, marked as category ***L***, by a forgetful functor $F_{L\text{-}K}$.

STEP 1:

A **→ Parameter**

Mor_A= {*P# → Para_name*, *P# → Para_value*}

Ob_A= {*P#*, *Para_name*, *Para_value* | *Para_name* = '*CYL*t', *Para_value* = '*0.007mm*'}

/* Category *A* is the subcategory of category *Parameter*, where *Para_name*='*CYL*t' and *Para_value*='*0.007*'*/

…

STEP10:

K **→ p1**

Mor_K = {*xop1*, *xpp1*, *xqp1*, *xrp1*, *xsp1*, *P#→Para_value*, *Fi#→ Filt_name_R*, *Fi#→Filt_name_G*, *Fi#→ Cutoff_wavelength*, *Fi#→ Upper_frequency*, *A#→ Asso_name*, *P#→Para_name*, *S#→Sampling_strategy*, *R#→Rest_name*, *Fi#→Upper_wavelength*, *Fi#→ Lower_frequency*}

Ob_K = {*R# * p1 P#* p1 A#* p1 Fi#* p1 S#*, *R#*, *P#*, *A#*, *Fi#*, *S#*, *Rest_name*, *Para_name*, *Para_value*, *Filt_name_R*, *Lower_frequency*, *Upper_frequency*, *Filt_name_G*, *Cutoff_wavelength*, *Upper_wavelength*, *Asso_name*, *Samp_strategy* | *Rest_name* ∈ *F*, *Para_name* ∈ *A*, *Para_value* ∈ *A*, *Filt_name_R* ∈ *C*, *Lower_ frequency* ∈ *J*, *Upper_ frequency* ∈ *G*, *Filt_name_G* ∈ *D*, *Cutoff_wavelength* ∈ *E*, *Upper_wavelength* ∈ *I*, *Asso_name*∈ *B*, *Samp_strategy* ∈ *H*}

STEP 11:

$$\boldsymbol{L} \xrightarrow{F_{L-K}} \boldsymbol{K}$$

Mor_L= { }

Ob_L = {*Rest_name*, *Para_name*, *Para_value*, *Filt_name_R*, *Lower_ frequency*, *Upper_ frequency*, *Filt_name_G*, *Cutoff_wavelength*, *Upper_wavelength*, *Asso_name*, *Samp_strategy*}

/*Category ***L*** is the subcategory of category ***K***, and it was obtained from category ***K*** by a forgetful functor $F_{L\text{-}K}$*/

From the above steps for query, we can know that in each step of the query, the returned result is an independent category; thereby the closure of the query is realized.

3. CONCLUSIONS

The complete style of drawing indication for cylindricity consistent with GPS standard system was proposed. Categorical data modeling was employed to integrate the specifications and verification for cylindricity. Firstly, the entities and their relationships in cylindricity were represented and stored by categories, objects and arrows, and the categories can be extended flexibly; secondly, the relationships between objects/morphisms in different categories can be refined through construction of pull backs and various functors in category theory; finally, the query and its closure problems of the model was realized by the construction of structures such as forgetful Functor and subcategory. In summary, the categorical modeling method makes the representation of entities and their relationships in cylindricity more simple, clear and flexible and it was used successfully in the integrated information system for geometrical characteristics.

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