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A Folk Evaluation Approach for Part Standardization

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Abstract

Product design standardization is a prevailing approach to promote the speed and quality of product development. Facts have proven that only cross-enterprise and large-scope standardization can exert the effect of standardization sufficiently. The traditional statistical methods of parts spectrum only apply within the enterprises; thus, a new approach is required for part standardization in a large scope. In this study, a folk evaluation approach for part standardization is proposed. This approach combines the philosophy of web 2.0 into the web-based parts library to facilitate part standardization in a large scope. According to the differences of evaluation data sources, the folk evaluation method includes two methods, namely, digg-based evaluation and user requirement-based evaluation. The technique details are discussed in this study, and the instance cases are conducted to demonstrate the method.

Key words

Part standardization, folk, web2.0, web-based parts library

1. Introduction

Product design is not only a link in the product production chain but also affects the entire product production and product quality [1]. Design standardization is a technique in engineering design that aims to reduce the number of parts within a product. The idea of design standardization is to reuse the preexisting design knowledge and design results as far as possible by modularization and serialization of the product and generalization and standardization of a part[2][3]. Design standardization has been proven an effective technique to improve the quality and shorten the cycle of product development. Part standardization and product modularization is the fundamental technique in design standardization philosophy.

Products are often made of parts (parts are divided into standard part, interchangeable part and customized (special purpose) part in design standardization philosophy [1]. Generally, with high quantities and different kinds of products grouped to implement standardization analysis, more interchangeable parts can be obtained from different products and used. At the same time, the quantity of customized parts in one kind of product can be reduced. Gu [4] revealed that only cross-enterprise and large-scope standardization of mechanical parts can exert the effect of standardization sufficiently. That is, the effect of part standardization is not as good as our assumption if the work is limited within one manufacturing enterprise. If all of the complete machine manufacturers and parts manufacturers in the industry can participate in this standardization work, then the results can be satisfactory. Internet technology has provided the conditions to achieve cross-enterprise and large-scope standardization of mechanical parts.

The procedure of part standardization analysis can be illustrated as follows: First, the usage frequency of parts is counted in the enterprise. The traditional statistical methods are parts name-based or group technology-based [3]. If the part usage frequency is greater than a certain threshold (the threshold is set to 5% [3], then these similar parts are considered the standardization objects. Second, the frequency spectrum of the standard elements in this group of similar parts (standard elements refer to the geometric form, function elements, function elements configuration, and main geometric dimensions of the part) are analyzed. Finally, the distribution of these standard elements is used to guide part standardization. In the Internet environment, such frequency spectrum analysis is difficult to apply because of the numerous enterprises and parts involved and the condition of these enterprises is in a state of flux.

A parts information exchange platform and a web-based parts library platform have been developed to facilitate information exchange between parts supplier and complete machine manufacturer in the Internet environment. Successful cases of web-based parts library have illustrated that this platform not only integrates and exchanges dispersed parts information and provides cost-free computer-aided design (CAD) models, but also collects complete information on various parts manufacturers and machine manufacturers [5-7]. Thus, the web-based parts library platform is a suitable tool to achieve part standardization and product modularization in a large scope.

The Internet is currently entering the web 2.0 era [8]. Various social tools (i.e., blogs, social networking service, wiki, and folksonomy) allow users to interact and collaborate with each other in a social media dialogue as creators of user-generated content in a virtual community [9]. In this study, the authors propose a new method called folk evaluation, which combines the philosophy of web 2.0 with the web-based parts library to facilitate part standardization in a large scope. Moreover, the distributed parts library management system—WebParts[10,11]—is used as the basis in conducting this research.

The remainder of the paper is organized as follows: The basic concepts of part standardization and web-based parts library are introduced in Section 2. The framework of the folk evaluation approach for part standardization is proposed and the technique details and instance cases is described in Section 3. Finally, the summary and future works are presented in Section 4.

2. Some Basic Concepts of Part Standardization and Parts Library

2.1 Basic concept of part standardization

According to references [2,3], four basic standardization elements are considered when analyzing the parts in the standardization procedure. The four basic standardization elements are the function element of the part, the geometric form of the part, the configuration of the function element, and the main geometric dimensions. Part standardization can be divided into four grades in terms of the different standardization degrees of these four standardization elements (Fig.1).

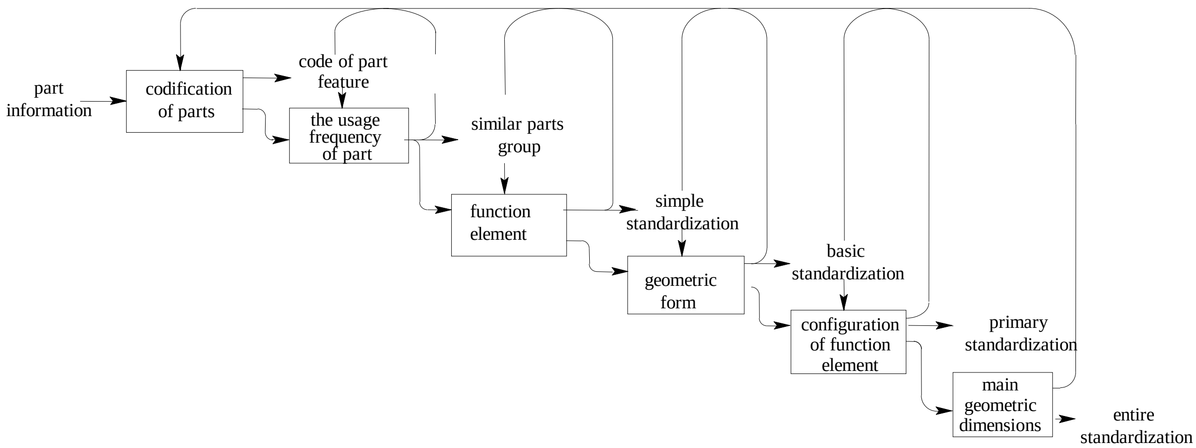


Fig.1. The four basic standardization grades of parts

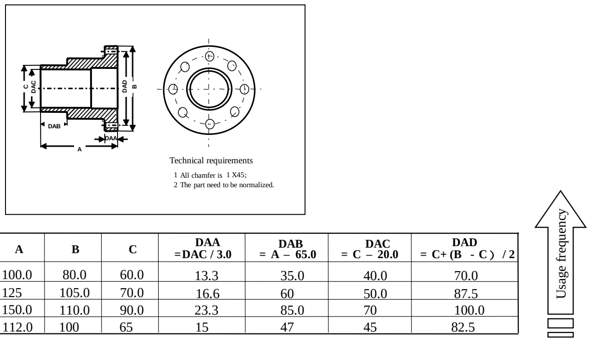
(1) Simple standardization: Only the function elements in the group of similar parts are standardized.

(2) Basic standardization: The function elements and the geometric form in the group of similar parts are standardized.

(3) Primary standardization: The fundamental elements, function elements, geometric form, and configuration of the function element in the group of similar parts are standardized.

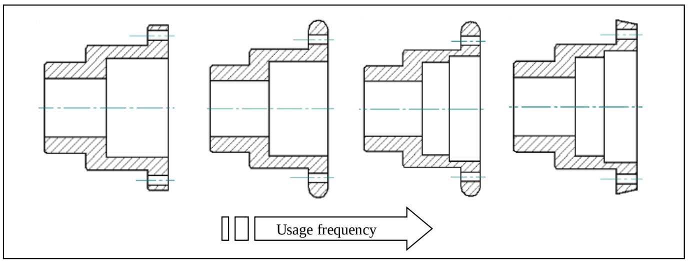
(4) Entire standardization: The four basic standardization elements in the group of similar parts are all standardized. Entire standardization indicates that all parts in this group of similar parts are identical, that is, the entire standardized part is the standard part.

In this study, we discuss primary standardization and entire standardization.



	A	B	C	DAA =DAC / 3.0	DAB = A − 65.0	DAC = C − 20.0	DAD = C+ (B - C) / 2
0001	100.0	80.0	60.0	13.3	35.0	40.0	70.0
0002	125	105.0	70.0	16.6	60	50.0	87.5
0003	150.0	110.0	90.0	23.3	85.0	70	100.0
0004	112.0	100	65	15	47	45	82.5

(a) Sorting of same structure parts, main geometric dimensions standardization--entire standardization



(b) sorting result of structure similar parts -- primary standardization

Fig. 2. The group of similar parts in two levels

The group of similar parts in this study contains two levels, namely, (1) same structure level (class): the standardized result is entire standardization (as shown in Fig. 2a) and (2) similar structure level (class): the standardized result is primary standardization (as shown in Fig. 2b).

2.2 Basic concept of parts library [12, 13]

Library end user: The library end user is usually an operator searching for parts to be used for some purpose. In this study, the user is referred to as the library end user.

Simple family of parts: A set of parts to which a parts supplier attributes a name, such that each part can be distinguished from the other parts by means of the values of certain attributes. If the set contains more than one element, then the parts supplier describes the ordered lists of attributes that shall be defined to ensure identification of each element in the set.

Library data supplier (or supplier): An organization that delivers a library in the standard format defined in ISO13584 and is responsible for its content.

3. Folk evaluation approach for part standardization

3.1 The framework of our approach

The word “folk” originated from the term “folksonomy” in web 2.0 philosophy [14,15]. In this study, folk means the data used to guide part standardization from the library end user. The framework of this approach is shown in Fig. 3. The core idea of this approach is to construct the evaluation index by utilizing the statistics of the usage status of parts resources and the user behavior in the web-based parts library. The evaluation index is used instead of the statistics of usage frequency in the traditional part standardization method. The realization mechanism of this approach is also shown in Fig. 1. The part with high index (i.e., frequently used [or downloaded] by users) will be pushed to latent users, which may significantly increase the quantity of orders. The part with low index (i.e., seldom used (or downloaded)by users) will diminish from the market because the quantity of orders decreased.

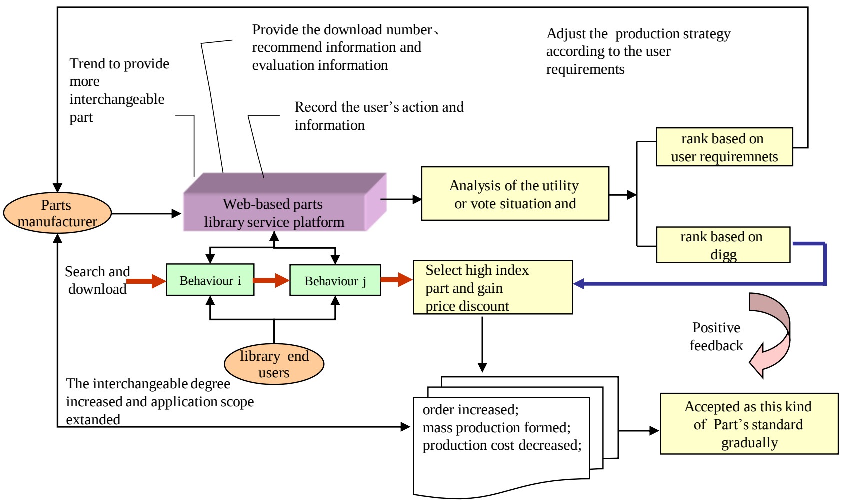


Fig. 3. The framework of folk evaluation for part standardization.

According to the different evaluation data sources, the approach involves two methods, namely, digg-based evaluation and user requirement-based evaluation. The technique details of these methods will be discussed in Sections 3.2 and 3.3.

3.2 Digg-based evaluation method

The term "digg" originated from the website "digg.com." The core idea of digg is to let users (folk) discover, share, and recommend web content. Members of the community could submit a webpage for general consideration. Other members could vote that page up ("digg") or down ("bury") [16]. Digg means "score adding" and bury means "score reducing," which is similar to the voting mechanism. When the number of diggs increases to a certain value, the webpage or web content can be selected from the buffer and recommended to the readers.

Our digg-based evaluation method is employed to digg the parts in the web-based parts library. Then, the "digg" result will be used to rank the parts in the web-based parts library. The empirical value of the user is considered and each library user will be assigned a weight, called "user weight" in this study, to guarantee the availability and specialization of the evaluation.

The user weight can be derived by tracking the operation behavior of the user in the web-based parts library. The tracked data will be stored in a database. Through the analysis and statistics of these data, the user weight can be allocated.

Considering the digg mode and characteristics of users in the web-based parts library, the factors that will affect the user weight are divided into three types in this study.

(1) Acceptance degree of the user: The acceptance degree of the user reflects the degree of favoritism, faithfulness, and attachment of the user to the web-based parts library. The value of the acceptance degree of the user can be decided by the visit times of the user, the download number of parts by one user, or the number of favorite parts in the favorites of the user.

We suppose that the user set is denoted by $X = \{x_i\}_{i=1,\ldots,n}$, where n is the total number of users in the web-based parts library platform. We let l_i be the log-in times of one user and f_i be the number of favorite parts in the favorites of this user (in our system, once the CAD model of one part is downloaded by one user, the information of this part will be integrated into his/her favorites). The acceptance degree of user x is denoted by $U_{ac}(x)$, and $U_{ac}(x)$ can be calculated according to reference [17] and the transfer degree function defined in reference[18], as follows:

$$U_{ac}(x) = \frac{1}{1+\exp\left(-\frac{n \cdot l_i}{\sum_{i=1}^{n} l_i}\right)} \cdot \frac{1}{1+\exp\left(-\frac{n \cdot f_i}{\sum_{i=1}^{n} f_i}\right)} \tag{1}$$

(2) Contribution degree of the user: The contribution degree of the user can be calculated using the number of diggs of one user. When the digged part is recommended and ranked in the top 10 parts list in the simple family of one part, the number of digged parts can be counted and used to calculate the contribution degree of the user.

We suppose that the digged number of user x is v_i, the number of digged parts that satisfied the aforementioned condition is r_i, and the set Y is all of the user sets who had ever digged this simple family of parts, and Y is defined as $Y = \{x_i\}_{i=1,\ldots,m}$, where $m \leq n$. Then, the contribution degree of user x is denoted by $U_{con}(x)$, and $U_{con}(x)$ can be calculated using the following equation:

$$U_{con}(x) = \frac{1}{1+\exp\left(-\frac{m \cdot v_i}{\sum_{i=1}^{m} v_i}\right)} \cdot \frac{1}{1+\exp\left(-\frac{m \cdot r_i}{\sum_{i=1}^{m} r_i}\right)} \tag{2}$$

(3) Preference degree of the user: Our algorithm supposes that the digged results are considered only on the condition that the user is highly interested in this simple family of parts to ensure the reliability of the digg results. The preference degree of the user can be calculated based on the operation behavior of the user in the web-based parts library.

From the discussion, we learned that, when the calculation refers to a certain simple family of parts or an instance of the simple family of parts, the preference degree of the user is meaningful.

Based on the researches of LI [19] and Pennock [20], the types of operation behavior of the users and related marks in web-based parts library are defined in Table 1.

Table 1. The types of user behavior and the related mark

Type of behaviour	Grade of behaviour	Mark	State
A query	A1 query	0.1	input the keywords of part name
B look up	B1 open	0.2	click the leaf node in the hierarchical parts classification tree or query one simple family of parts in the list
	B2 browse1	0.3	look up the definition table of one simple family of parts(part instances)
	B3 browse2	0.4	look up the 3D model of this part online
C reserve	C1 collect	0.5	put the part in the favorites
	C2 download	0.8	download CAD model
D return visit	D1 return visit	acculmulation	visit one simple family of parts serval times or download another instance in this simple family of parts

The operation behavior can be recorded by a user behavior log file on the server side. As shown in Table 1, the "return visit" behavior means that the user is interested. Thus, the more frequent the user returns to browse a simple family of parts, the more interested in this simple family of parts the user is. The mark of "return visit" operation is "accumulation" directly.

We suppose that $Z = \{x_i\}_{i=1,\dots,q}$ is the set of users who had visited a simple family of parts CM_k, where the number of such users is q. The preference degree of user x to one simple family of parts CM_k is denoted by $U_{\text{pre}}(CM_k)$, and $U_{\text{pre}}(CM_k)$ can be calculated as follows:

$$U_{pre}(CM_k) = \sum_{i=1}^{P} \max(op_j) \tag{3}$$

where $\max(op_j)$ is the highest score of the operation behavior of user x to one simple family of parts CM_k each time. For example, one operation set of user x to CM_k includes query, open, browse1, and add in favorite, as illustrated in Table 1, that is, $\{A1, B1, B2, C1\}$. Then, the operation score of user x to CM_k is $\max(A1, B1, B2, C1) = 0.5$. P is the visit times of user x to one simple family of parts CM_k.

The preference degree of the user should be normalized to unify the scale of the acceptance degree of the user, the contribution degree of the user, and the preference degree of the user. Thus, the min–max method is used:

$$U'_{pre}(CM_k)_i = \frac{U_{pre}(CM_k)_i - U_{pre}(CM_k)_{\min}}{U_{pre}(CM_k)_{\max} - U_{pre}(CM_k)_{\min}} \tag{4}$$

where $U_{pre}(CM_k)_{max}$ and $U_{pre}(CM_k)_{min}$ are the maximum and minimum values of $U_{pre}(CM_k)$, respectively. $U'_{pre}(CM_k)_{max}$ is the normalized $U_{pre}(CM_k)$.

As analyzed previously, the digg weight of user x can be calculated using the following equation (the contribution and preference degree of the user are given more importance than the acceptance degree of the user in our method):

$$\omega_i = 0.5U'_{pre}(CM_k) + 0.3U_{con}(x) + 0.2U_{ac}(x) \tag{5}$$

Obviously, if one registered user has no operation behavior on one kind of part, then the value of the preference degree of the user is equal to 0.

The system forbids the parts manufacturers or vendors to vote for their products to ensure fairness and reliability of the evaluation.

In this method, the evaluation and rank are referred to the group of similar parts we have defined previously, i.e., structure same class and structure similar class.

We suppose that, if the number of users who voted for one part or part family is h, the vote count of user i is b_i, and the user weight of i is ω_i, then the digg result of one part or part family is obtained as follows:

$$E = \sum_{i=1}^{h} \omega_i b_i \tag{6}$$

According to Equation (6), the part will be ranked, with a high score indicating that the part or part family is preferred by most users and will be recommended. Then, this part or part family will become the standardized object.

Fig. 4 exhibits the part digg result.

Fig. 4. The instance case of the digg-based result.

3.3 User requirement-based approach

The digg-based evaluation method is based on the existing parts resources in the web-based parts library. However, the requirement of the complete machine manufacturer is not considered in this method. The authors proposed the user requirement-based method to compensate for the disadvantage of the digg-based evaluation method. The evaluation results can be used to guide the parts manufacturers to produce the parts reasonably and to improve the interchangeability and standardization of parts.

Usually, the query process in a web-based parts library is as follows [10, 11]: (1) the user inputs the query conditions through the query interface; (2) the system verifies the target space of the query, that is, determine the kind of part family that is close to the query; and (3) identify which part instance matches the query condition in the target space. Thus, the query conditions can be regarded as the user requirements.

Two ways to achieve the user requirements are as follows: (1) Surveying the customer needs through an interface designed to acquire the user requirements. This method acquires the requirements directly, but the user needs to input his/her requirements solely and the results rely on the willingness of the user mostly. Thus, inaccurate results are inevitable. (2) Recording the query conditions that the user inputs through the search interface of the web-based parts library. This approach acquires the user requirements by back-end analysis and hardly affects the users. The steps of the user requirement-based method are introduced in the subsequent sections.

1) Acquire the user requirements

The user inputs the query conditions through the search interface. A user behavior tracking module is designed to record the query conditions of each user. The query actually reflects the function and structure requirements of the parts.

After recording all of the query conditions, the subsequent step is requirements filtering. This step aims to eliminate noise records. For example, the user may input the query conditions optionally only to experience the function of the system. Such query records do not reflect the real requirements of the user. A user control strategy is proposed in this method and the system only considers certain query conditions of users to avoid such noise records. A certain user can be distinguished by the value of the acceptance degree of the user ($U_{ac}(x)$), which has been defined in Section 3.2. If the value of $U_{ac}(x)$ is greater than a certain threshold, then the query of the user is adopted.

2) Evaluation method

(1) Primary standardization: tag-based part standardization

The authors proposed a tag-based coding system to code the simple family of parts to illustrate the features of the part semantically. In this method, the tag is used instead of the numeric code in group technology. Similar to other web 2.0-based systems, the part in the web-based parts library can be tagged by the resource provider or user. The tag types used in the web-based parts library is shown in Fig. 5. Thus, the system had also provided a tag-based search interface in our web-based parts library.

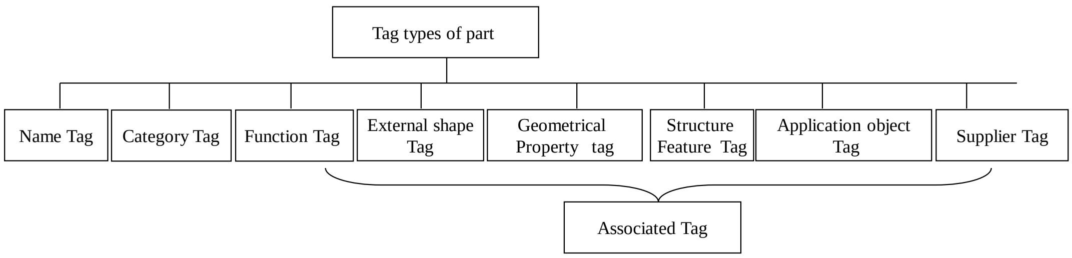


Fig. 5. Tag types of our tag-based coding method.

We suppose that the set of users who have queried one simple family of part CM is denoted by $X = \{x_i\}_{i=1,\ldots,K}$. Moreover, the query condition of user x_k can be denoted as $Q_k(\mathrm{CM}) = \left\{\{t_k^{C1}\}, \{t_k^{C2}\}, \ldots, \{t_k^{Cn}\}\right\}$, where the superscript of t_k^{Ci} denotes the type of tag, the subscript denotes the user x_k, and $\{t_k^{Ci}\}$ denotes that the user have used several tags to illustrate one type of tag. Given that only the feature-related tag should be considered in the standardization process, a user–tag type matrix can be formed, as follows:

$$UT = \begin{bmatrix} \{t_1^{C1}\} & \cdots & \{t_1^{Cn}\} \\ \vdots & \ddots & \vdots \\ \{t_K^{C1}\} & \cdots & \{t_K^{Cn}\} \end{bmatrix}_{K\times n} \tag{7}$$

Each column in the matrix corresponds to one tag type, and each row in the matrix corresponds to a query of the user.

In our method, we use annotation frequency to describe the tag usage frequency to one simple family of parts. We suppose that if $l(l \leq K)$ users use the tag t_j^{Ci} to tag one feature Ci in CM, then the annotation frequency is defined as:

$$TF_{t_j^{Ci}} = \frac{l}{K} \tag{8}$$

The highest value of $TF_{t_j^{Ci}}$ indicates that most users prefer that the feature type Ci (for example, the structure feature) of CM should have the feature t_j.

For example, Fig. 6 shows the statistical results of the tags used to illustrate the external shape type of one rotational machine part. Most users prefer the shape of parts with unidirectional step.

After counting all columns of the user–tag type matrix, all of the tags with the highest value of $TF_{t_j^{Ci}}$ consist the semantic coding model of this simple family of parts.

$$GM(CM) = \{\{t_j^{Ci}\} \mid s.t. \max(TF_{t_j^{Ci}})\} \tag{9}$$

This model expresses the user requirements for the function and form features of this simple family of parts. These results can encourage the parts manufacturer to adjust their design and production strategy, as illustrated in Fig. 2. In accordance with the introduction in Section 2, this is primary standardization.

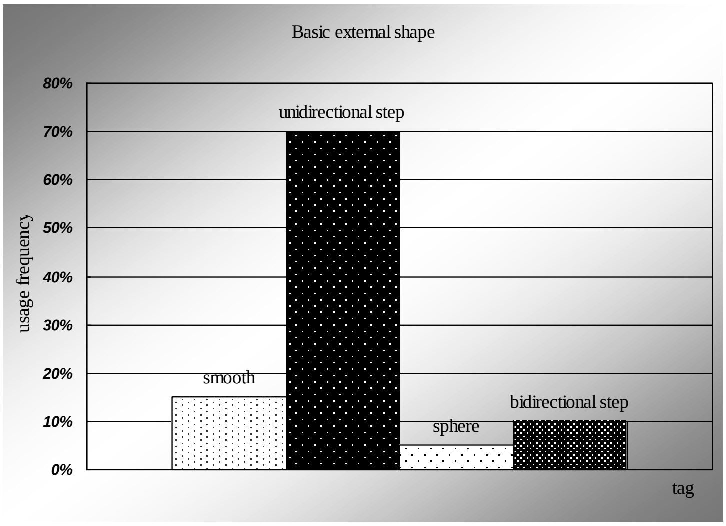


Fig. 6. The statistical result of the basic external shape of one part

(2) Entire standardization: characteristics-based standardization method

The values of part characteristics include character and numerical type. The value of numerical type characteristic is a certain value or a range value. The value of character type characteristic is enumerated type data. For example, the value domain of the header shape of the internal hexagonal cylindrical head bolt is countersunk head, half-round head, or cheese-head.

Each part instance of one simple family of parts can be described by a vector:

$$P^i = < p_1^i, p_2^i, \cdots, p_{nc}^i > \tag{10}$$

where nc is the number of the part characteristic and p_j^i is the value of characteristic j.

Then, the query of the user can be described as:

$$Q = < C, (o_1, p_{j1}), (o_2, p_{j2}), \cdots (o_m, p_{jm}) > \tag{11}$$

where $o_{1,\ldots,m}$ is the Boolean operator. For numerical type properties, the operator is "=," ">," and "<." For character type properties, the operator is "contain" or "exact match." In this study, the query interface lists all of the possible values of this property. Thus, the operator is "exact match."

From the viewpoint of function and structure, the two types user requirements are as follows: (1) function requirements, such as the output power, the efficiency, the load, and the force, and (2) structure requirements (geometric parameters), such as the diameter of the axle and the length of the box. The query of the user is the combination of these two kinds of requirements.

According to the design methodology, the product design process is in the following order: function solutions → principle solutions → structure solutions. Thus, the function requirements should be analyzed prior to the statistical analysis of the structure parameter. The user requirements are clustered according to the function requirements, and the geometric parameters distribution graph is drawn under the constraints of the clustering results of function.

Qi [1] and Ma [21] revealed that the geometric parameters of the part are divided into interface parameter (variable parameter) and non-interface parameter (invariant parameter). In fact, according to the definition in reference [1], the interface parameter corresponds to the part characteristics defined in the standard ISO13584 [13] or the article characteristic in tabular layout of article characteristics [22]. Non-interface parameter (invariant parameter) has an indirect effect on the part function or can be derived from the interface parameter by constraint relationships. Therefore, only the interface parameters (variable parameters) should be counted and analyzed.

The values of each part characteristic require certain resources (i.e., manufacturing and human resources) to ensure the fast production of the parts [21]. Thus, the clustering results should conform to a series of preferred numbers [23, 24]), such that the enterprise can arrange the production using the existing resources. In this study, the R10 series is adopted.

The inputted queries from the search interface are discrete values. The clustering method is a better solution to deal with these discrete data and determine the proper value to guide the standardization of these geometric parameters. These discrete values could be clustered together and the center value of each cluster can be used as the basis of the structural standardization of the parts. As shown in Fig. 2, the standardization result is entire standardization.

Several cluster analysis algorithms have been proposed previously. In this study, the *k*-means clustering is used [25]. The subsequent case will be introduced to illustrate this method in detail.

A shrink disk is used as the case, and a total of 261 query records are obtained from the back-end server (as shown in Fig. 7).

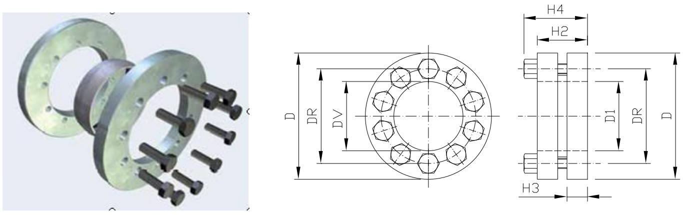
The Waikato Environment for Knowledge Analysis (WEKA) [1] is used to cluster and automatically normalize numerical data.

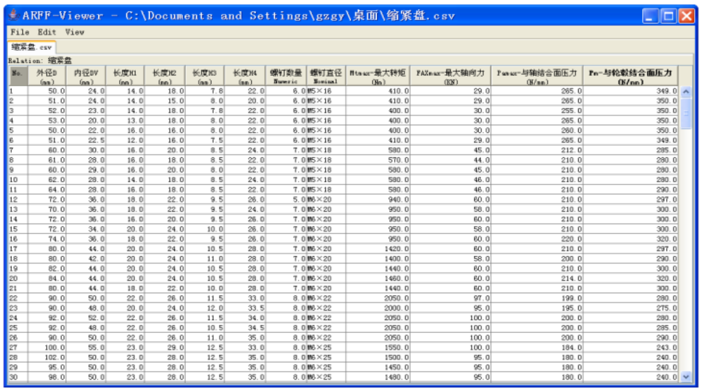
According to the working characteristics of the shrink disk, the parameters *D*, *DV*, and *H*2 are the key parameter or the characteristics of the shrink disk and the other parameters can be deduced from the three parameters. Thus, only these three parameters should be analyzed. Prior to clustering, the data should be preprocessed. The purpose of data preprocessing is to eliminate the deviation of the clustering results based on Euclidean distance caused by different units and ranges of the parts properties. In this process, also known as data normalization, the numerical

[1] The source code of WEKA can be obtained from the site http://www.cs.waikato.ac.nz/ml/weka.

type data are compressed into the interval [0,1] and character type data (enumerated type) are converted to a value of either 0 or 1.

From the aforementioned process, the geometric parameters are filtered under the clustering results of function requirements. According to the working characteristics of shrink disk, the function requirement, i.e., maximum transmission torque, is selected. The optimal number of clusters should be confirmed first. The sum of squared error E is the evaluation index in *k*-means clustering. The optimal number of clusters can be determined by the relationship graph of the number of clusters and the sum of squared error E (Fig. 8). When the inflection point of the curve appears, the decay rate of the sum of squared error E slows down. In our case, three kinds of seed number are selected. The graph shows that, when the number of clusters reaches a certain level, the curves almost converge. That is, the number of clusters can be 10, 11, or 12. The number of clusters is selected as 12 in this study.

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Relation: 缩紧盘

No.	外径D (mm)	内径DV (mm)	长度H1 (mm)	长度H2 (mm)	长度H3 (mm)	长度H4 (mm)	螺钉数量 Numeric	螺钉直径 Nominal	Mtmax-最大转矩 (Nm)	FAXmax-最大轴向力 (KN)	Pwmax-与轴结合面压力 (N/mm)	Pn-与轮毂结合面压力 (N/mm)
1	50.0	24.0	14.0	18.0	7.8	22.0	6.0	M5×16	410.0	29.0	265.0	349.0
2	51.0	24.0	14.0	15.0	8.0	20.0	6.0	M5×16	410.0	29.0	265.0	350.0
3	52.0	23.0	14.0	18.0	7.8	22.0	6.0	M5×16	400.0	30.0	255.0	350.0
4	53.0	20.0	13.0	18.0	8.0	22.0	6.0	M5×16	400.0	30.0	265.0	350.0
5	50.0	22.0	16.0	16.0	8.0	22.0	6.0	M5×16	400.0	30.0	260.0	350.0
6	51.0	22.5	12.0	16.0	7.5	22.0	6.0	M5×16	410.0	29.0	265.0	349.0
7	60.0	30.0	16.0	20.0	8.5	24.0	7.0	M5×18	580.0	45.0	212.0	285.0
8	61.0	28.0	16.0	18.0	8.5	22.0	7.0	M5×18	570.0	44.0	210.0	280.0
9	60.0	29.0	16.0	20.0	8.0	22.0	7.0	M5×18	580.0	45.0	210.0	280.0
10	62.0	28.0	14.0	18.0	8.5	24.0	7.0	M5×18	580.0	46.0	210.0	280.0
11	64.0	28.0	16.0	18.0	8.5	22.0	7.0	M5×18	580.0	46.0	210.0	290.0
12	72.0	36.0	18.0	22.0	9.5	26.0	5.0	M6×20	940.0	60.0	210.0	297.0
13	70.0	36.0	18.0	22.0	9.5	24.0	7.0	M6×20	950.0	58.0	210.0	300.0
14	72.0	36.0	16.0	20.0	9.5	26.0	7.0	M6×20	950.0	60.0	210.0	300.0
15	72.0	34.0	20.0	24.0	10.0	26.0	7.0	M6×20	950.0	58.0	210.0	300.0
16	74.0	36.0	18.0	22.0	9.5	26.0	7.0	M6×20	950.0	60.0	220.0	320.0
17	80.0	44.0	20.0	24.0	10.5	28.0	7.0	M6×20	1420.0	60.0	210.0	297.0
18	80.0	42.0	20.0	24.0	11.0	28.0	7.0	M6×20	1400.0	58.0	200.0	290.0
19	82.0	44.0	20.0	24.0	10.5	28.0	7.0	M6×20	1440.0	60.0	210.0	300.0
20	84.0	44.0	20.0	24.0	10.5	28.0	7.0	M6×20	1460.0	60.0	214.0	320.0
21	80.0	44.0	18.0	22.0	10.0	28.0	7.0	M6×20	1440.0	60.0	210.0	300.0
22	90.0	50.0	22.0	26.0	11.5	33.0	8.0	M6×22	2050.0	97.0	199.0	280.0
23	90.0	48.0	20.0	24.0	12.0	33.5	8.0	M6×22	2000.0	95.0	195.0	275.0
24	92.0	52.0	22.0	26.0	11.5	34.0	8.0	M6×22	2050.0	100.0	200.0	280.0
25	92.0	48.0	22.0	26.0	10.5	34.5	8.0	M6×22	2050.0	100.0	200.0	285.0
26	90.0	50.0	22.0	26.0	11.0	35.0	8.0	M6×22	2050.0	100.0	200.0	290.0
27	100.0	55.0	23.0	29.0	12.5	33.0	8.0	M6×25	1550.0	100.0	184.0	243.0
28	102.0	50.0	23.0	28.0	12.5	35.0	8.0	M6×25	1500.0	95.0	180.0	240.0
29	95.0	50.0	23.0	28.0	12.5	35.0	8.0	M6×25	1450.0	95.0	180.0	240.0
30	98.0	50.0	23.0	28.0	12.5	35.0	8.0	M6×25	1480.0	95.0	180.0	240.0

Fig. 7. Original cluster data of the shrink disk

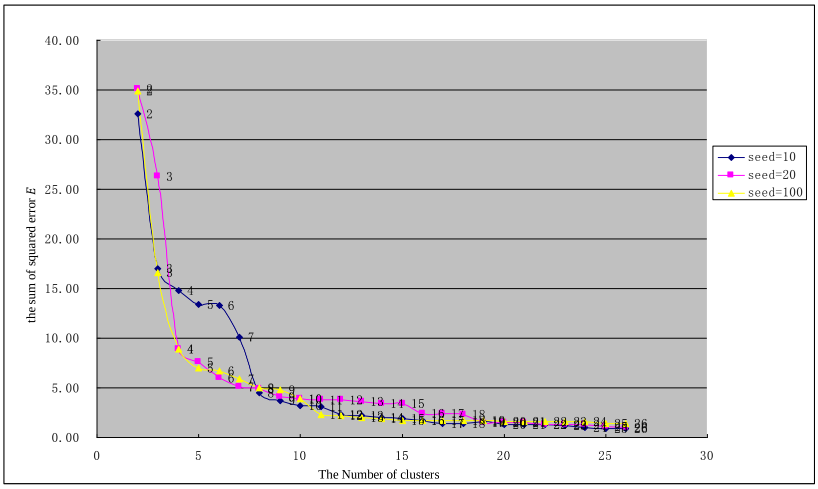
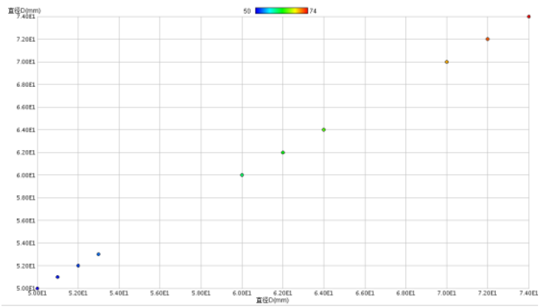


Fig. 8. The relationship graph of the number of clusters and the sum of squared error E.

From the clustering result (with 48 query records in cluster 5 (Fig. 9(a)), the value of the maximum torque ranges from 400 to 950 and the value of the diameter *D* ranges from 50 to 74. From the distribution graph of the diameter *D* (Fig. 9(b)), the diameter *D* is clustered into three ranges, namely, from 50 to 54, from 60 to 64, and from 70 to 74. The distance among these clusters meets the needs of the priority number system. The cluster center is 51, 61.2, and 72, and these values are rounded to 50, 60, and 72, respectively. The rounded values are recommended as the standard values of the diameter *D* for this kind of shrink disk.

序号	Mtmax-最大转矩...	FAXmax-最大轴向力...	Pamax-与轴结合面压力...	Pm-与轮毂结合面压力...	簇
1	410	29	265	349	clust5
6	410	29	265	349	clust5
88	410	29	265	349	clust5
93	410	29	265	349	clust5
175	410	29	265	349	clust5
180	410	29	265	349	clust5
4	410	30	265	350	clust5
91	410	30	265	350	clust5
178	410	30	265	350	clust5
2	410	29	265	350	clust5
89	410	29	265	350	clust5
176	410	29	265	350	clust5
3	400	30	255	350	clust5
90	400	30	255	350	clust5
177	400	30	255	350	clust5
5	400	30	260	350	clust5
92	400	30	260	350	clust5
179	400	30	260	350	clust5

(a)



(b)

Fig. 9. Clustering result (a) and the distribution graph of the diameter *D* (b)

4. Conclusion

Interchangeability and standardization are important contents and foundations of product modularization and design standardization. Traditionally, part standardization is implemented within the enterprise; however, efficiency is difficult to produce in standardization. The authors propose that part standardization must be implemented in a large scope to accelerate part evolution. (In this study, evolution means the transfer of customized parts into interchangeable parts and the transfer of interchangeable parts into standard parts as far as possible.) The development of web-based parts library makes this idea realizable and possible. Based on the web-based parts library and the related Standard ISO13584, a folk evaluation part standardization method is proposed and the related technique is introduced in detail. The core idea of this approach can be described as follows: A part standardization evaluation model is generated and the evaluation index is calculated based on the usage status of the parts resources in web-based parts library. The part with high index (i.e., frequently used [or downloaded] by users) will be pushed to latent users, which may significantly increase the quantity of orders. The increased orders will help the enterprise decrease production cost by mass production. The decreased cost will ensure the competitive superiority of product price and form a positive feedback cycle to accelerate the evolution process. Such self-organized standardization process will benefit the promotion of the development speed and quality of the product and achieve the "less variant interior and more diverse external" philosophy in the mass customization production mode.

Collaboration and specialization are development directions of the mechanical industry. Product modularization can support the collaboration among enterprises. The module produced by specialized parts manufacturer can help the complete machine enterprise produce customized products promptly. From the standardization perspective, modularization is the advanced form. From the product system perspective, the focus of modularization is component-level standardization (Tong, 2000). Thus, our future study will focus on how to use the proposed approach to promote module partition and module standardization.

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