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Parametric driven based generation and transformation of MBD mid-tolerance model[1]

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Abstract. A parametrically driven Model Based Definition (MBD) mid-tolerance model is proposed. First, the definition, vital significance and meaning of MBD mid-tolerance model are put forward. On the basis of comprehensively elaborating parameter design technology, one-to-one corresponding mathematical relation between feature constraint dimension and feature driving parameter is analyzed and mathematical relation between engineering dimension and feature driving parameter together with feature constraint dimension is further explained. Then mathematical expression between engineering dimension and parameter variable is established. Meanwhile, through analyzing the interrelation among dimensions by taking advantage of dimension chains, mathematical expressions between non-marking engineering dimension and driving parameter is established. Also the change law between marking engineering dimension and non-marking engineering dimension is specified and theoretical basis for generation and transformation of mid-tolerance model is provided. On this basis, a detailed process and specific algorithm of generation and transformation of mid-tolerance is proposed. Finally, a case used to verify the thought is feasible and relevant algorithm is proved to be accurate.

Key words. Parametrically driven MBD mid-tolerance model, feature parameter, engineering dimension, dimension chains..

1. Introduction

With the technological development of computer, software and digital manufacture, product definition technology has developed to fully 3D digital definition technology, called Model Based Definition (MBD), from two-dimensional CAD technology. The MBD technology is a technology to organize, express, show, operate

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and manage non-geometry manufacture information on product dimensions, tolerance, and manufacturing technology requirement on the basis of a 3D digital model, see [1–2]. It abandons two-dimensional engineering drawing, making the 3D digital model become the only vehicle of product information and making it the only evidence to convey design information in the manufacturing process. MBD technology changes the way of process design. Process design method and technology traditionally based on 2D engineering drawing or 3D model have not applied or satisfied requirement of this technology, so that computer-aided process design and planning technology based on fully 3D model is badly needed to realize fully 3D digital design and manufacturing, which transforms digital manufacturing technology [3–4].

Mid-tolerance is also named symmetry tolerance. Mid-tolerance model is a component geometry model built in the state of symmetry tolerance. MBD Mid-tolerance model is the component structure model built as nominal size in the state of symmetry tolerance and marks the engineering dimension with symmetry tolerance on the model by taking advantage of MBD technology. In the process of NC design, tool path of components has to be formed as mid-tolerance model or MBD mid-tolerance model, so as to improve working efficiency of NC program by technicians. When technicians design 3D process under current MBD technological condition, working procedure dimension is calculated under the condition of mid-tolerance [1–2]. After the 3D process design is completed, it is necessary to transfer the relevant working procedure dimensions to the maximum material dimension; finally the procedure MBD model is formed. Therefore, building of mid-tolerance model is meaningful and significant.

2. 3D parametric design based on feature

3D parametric design based on feature is (by establishing component parametric 3D model using a group of parameter to show or engage the feature dimensional relation) only adjusting or changing one or several parameter values in the group of parameters without entering all definite feature dimensional values to automatically change all relevant feature dimensions and revise and control all feature geometry forms of model, so as to realize accurate 3D modeling of components [5–6]. Parametric design technology may improve design efficiency and flexibility of components by taking advantage of powerful model modification method to avoid fussy repetitive working, becoming the efficient technological measure for original design, product modeling, deformation design of modification series, multi-plan comparison and dynamic and concurrent designs [7–8].

If $D_{\mathrm{F}} = \{D_{\mathrm{F}1}, D_{\mathrm{F}2}, ..., D_{\mathrm{F}n}\}$ is used to indicate n feature constraint dimensions of the component, every feature dimension corresponds to a parameter, and $X = \{X_1, X_2, ..., X_n\}$ is used to express n self-defined parameter variables of driving dimensional constraint components, then

$$D_{\mathrm{F}} = A \cdot X \,, \tag{1}$$

where A is an $n \times n$ unitary matrix.

Figure 1 shows a shaft sleeve component formed by rotation of sketch features or generated by single feature combination. The location relation of geometrical elements of the component on the axis is completely defined by three feature constraint dimensions (expressed by the dashed lines) as D(AB), D(BD), D(CD). If parameter variables AB, BD and CD drive such three feature constraint dimensions as D(AB), D(BD) and D(CD), the component location relation of geometrical element on axis will be determined by the AB, BD and CD parameter variables. Feature constraint dimension and parameter variable of the component have the following one-to-one corresponding relation.

$$\begin{bmatrix} \mathrm{D(AB)} \\ \mathrm{D(BD)} \\ \mathrm{D(CD)} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \mathrm{AB} \\ \mathrm{BD} \\ \mathrm{CD} \end{bmatrix} .$$

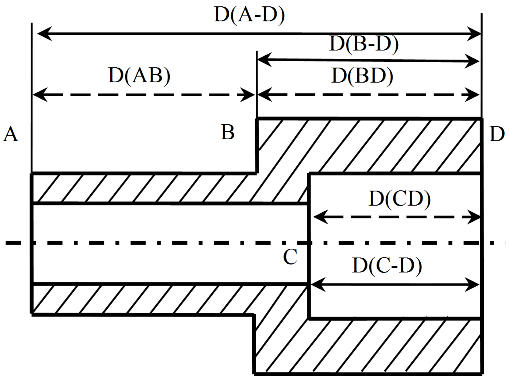

Fig. 1. Shaft sleeve component

3. Relation between design dimension and feature parameter

Engineering dimension can be expressed by feature constraint dimensions. If $D = \{D_1, D_2, ..., D_n\}$ expresses n engineering dimensions of the component P, then

$$D = B \cdot D_{\mathrm{F}} . \tag{2}$$

In the above formula

$$B = \begin{bmatrix} a_{11} & \dots & a_{1n} \\ \dots & \dots & \dots \\ a_{n1} & \dots & a_{nn} \end{bmatrix} , \quad a_{ij} \in (-1, 0, 1) .$$

After substituting expression (1) into (2), then

$$D = B \cdot D_{\mathrm{F}} = BA \cdot X = B \cdot X , \tag{3}$$

in other words

$$\begin{bmatrix} D_1 \\ \ldots \\ D_n \end{bmatrix} = \begin{bmatrix} a_{11} & \ldots & a_{1n} \\ \ldots & \ldots & \ldots \\ a_{n1} & \ldots & a_{nn} \end{bmatrix} \begin{bmatrix} X_1 \\ \ldots \\ X_n \end{bmatrix}. \tag{4}$$

From (4) it can be seen that every engineering dimension can be expressed by algebraic relations of parameter variables. From (3) we easily obtain

$$X = B^{-1} \cdot D\,. \tag{5}$$

It is clear that from (5) every parameter variable can be expressed by algebraic relation of engineering dimensions. That is, the marked group of engineering dimensions can solely define a group of parameter variables.

As is shown in Fig. 1, shaft sleeve components have four geometrical elements on the axis. Therefore, the complete engineering diagram indicating components should be marked with three engineering dimensions. Symbols D(A-D), D(B-D), and D(C-D) in the figure represent one of annotation schemes of the axis engineering dimension. They have algebraic relation with dimensional parameters. Among which, engineering dimension D(B-D) is determined by parameter BD and engineering dimension D(C-D) is determined by parameter CD, while engineering D(A-D) is the sum of the parameters AB and BD. Thus, the engineering dimensions and parameter variables of the component have following corresponding relations

$$\begin{bmatrix} D(A-D) \\ D(B-D) \\ D(C-D) \end{bmatrix} = \begin{bmatrix} 1 & 1 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} AB \\ BD \\ CD \end{bmatrix}.$$

4. Law of interaction between dimensions

4.1. Dimension relations

Interrelation of component engineering dimensions needs to be expressed and calculated by dimensional chains. Any dimensional chain is composed of component link and closing link and every dimensional chain has a single closed ring. Component link directly guarantees the dimension while closing link indirectly guarantees the dimension through other dimensions. According to marking requirements of component engineering dimension, dimensions directly marked on the component are component links, while the rest are closing links.

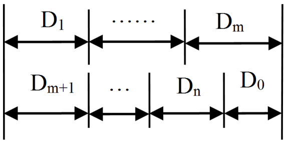

Fig. 2. Dimensional chains

As shown in Fig. 2 containing a linear dimensional chain composed by $n+1$ rings, the dimension D_0 is the closing ring and $D_1 - D_n$ are the component rings. The basic dimension of the closing ring equals to the sum of basic dimensions of increasing rings minus the sum of basic dimensions of decreasing rings, so that

$$D_0 = \sum_{z=1}^{m} D_z - \sum_{j=m+1}^{\mathrm{n}} D_j \,. \tag{6}$$

In this In this expression, D_0 is the basic dimension of the closing link, D_z denotes the basic dimension of the increasing link, D_j stands for the basic dimension of the decreasing link, m is the number of the increased links and n denotes the number of dimensional chains. Meanwhile, from the expression (6) we can deduct that

$$\Delta D_0 = \sum_{z=1}^{m} \Delta D_z - \sum_{j=m+1}^{\mathrm{n}} \Delta D_j \,. \tag{7}$$

From formula (7), we can see that when certain dimension in the component link is changed and other component links are not changed, the dimension of the closing links will change correspondingly. The details follow

1. When the component link is an increasing link, the closing link would change in the same direction. That is, the closing link increases with increasing of the component link and decreases with decreasing of the component link.

2. When the component link is a decreasing ring, the closing link would change in the reverse direction. That is, the closing link increases with decreasing of the component link and decreases with increasing of the component link.

4.2. Relation between closing link and driving parameter

From expression (6) we have

$$D_0 = \begin{bmatrix} 1 & ... & 1 & -1 & ... & -1 \end{bmatrix} \begin{bmatrix} D_1 \\ ... \\ D_m \\ D_{m+1} \\ ... \\ D_n \end{bmatrix} = \tag{8}$$

Introducing of expression (4) into (8), we can see that

$$D_0 = \begin{bmatrix} 1 & ... & 1 & -1 & ... & -1 \end{bmatrix} \cdot \begin{bmatrix} a_{11} & ... & a_{1n} \\ ... & ... & ... \\ a_{m1} & ... & a_{mn} \\ a_{(m+1)1} & ... & a_{(m+1)n} \\ ... & ... & ... \\ a_{n1} & ... & a_{nn} \end{bmatrix} \cdot \begin{bmatrix} X_1 \\ ... \\ X_m \\ X_{m+1} \\ ... \\ X_n \end{bmatrix} =$$

$$= \begin{bmatrix} Q_1 & \dots & Q_n \end{bmatrix} \cdot \begin{bmatrix} X_1 \\ \dots \\ X_m \\ X_{m+1} \\ \dots \\ X_n \end{bmatrix} = Q_1X_1 + \dots + Q_nX_n, \tag{9}$$

where

$$Q_i = a_{1i} + a_{2i} + \cdots + a_{mi} - a_{(m+1)i} - \cdots - a_{ni} .$$

From expression (9) we can see that not only there is algebraic relation between marking engineering dimension and driving parameter of the component, but also non-marking engineering dimension can be expressed by a linear driving parameter. Therefore, under the condition of a known component of the driving parameter, all dimensions of the component are definite and can be obtained by calculating the driving parameter.

5. Results

An example was used to verify the thought that realizes the automatic generation and transformation of MBD mid-tolerance model through parameter driving. As shown in Fig. 3 the shaft sleeve is a component structure and axis is geometrical surface number. Mid-tolerance generation and transformation of radical dimension is the same as axis dimension. Radical dimension is ignored for simplifying. As shown in Fig. 4 the MBD model is created, when the component is marked with dimension and tolerance as the maximum material principle. According to its structural characteristics, the buildup feature constraint dimension and corresponding driving parameter are shown in Table 1. The relation between the design dimension and parameter of the component is shown in Table 2.

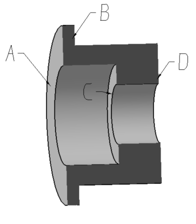

Fig. 3. Component structure and surface number

Table 1. Component feature parameters

constraint dimension	driving parameter
D(AB)	AB
D(AC)	AC
D(BD)	BD

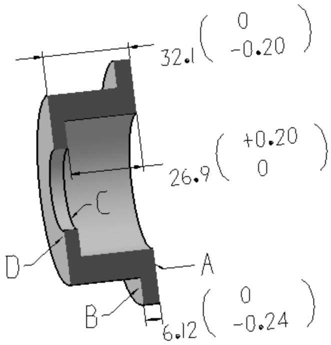

Fig. 4. Maximum material MBD model

Table 2. Relation between component design dimension and parameter

design dimension	parameter expression
D(A-B)	AB
D(A-C)	AC
D(B-D)	BD
D(A-D)	AB+BD
D(C-D)	AB+BD-AC

According to above information, the design dimension D, feature constraint dimension D_{F}, driving parameter X and its transition matrix B of the component are built as follows

$$D=\begin{bmatrix} D(A-B) \\ D(A-C) \\ D(A-D) \end{bmatrix} \quad D_F=\begin{bmatrix} D(AB) \\ D(AC) \\ D(BD) \end{bmatrix} \quad X=\begin{bmatrix} AB \\ AC \\ BD \end{bmatrix} \quad B=\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 1 & 0 & 1 \end{bmatrix}.$$

The inverse matrix of B is

$$B^{-1}=\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ -1 & 0 & 1 \end{bmatrix}.$$

Therefore, according to (5)

$$X=\begin{bmatrix} AB \\ AC \\ BD \end{bmatrix}=\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ -1 & 0 & 1 \end{bmatrix}\begin{bmatrix} D(A-B) \\ D(A-C) \\ D(A-D) \end{bmatrix},$$

In addition, the component has two closing links of $D(B-D)$ and $D(C-D)$. The dimensional chains are shown as Fig. 5.

According to (8), the driving parameter expression of closing links is deduced as follows

$$D(B-D)=\begin{bmatrix} -1 & 0 & 1 \end{bmatrix}\begin{bmatrix} D(A-B) \\ D(A-C) \\ D(A-D) \end{bmatrix}=$$

$$=\begin{bmatrix} -1 & 0 & 1 \end{bmatrix}\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 1 & 0 & 1 \end{bmatrix}\begin{bmatrix} AB \\ AC \\ BD \end{bmatrix}=\begin{bmatrix} 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} AB \\ AC \\ BD \end{bmatrix}=BD$$

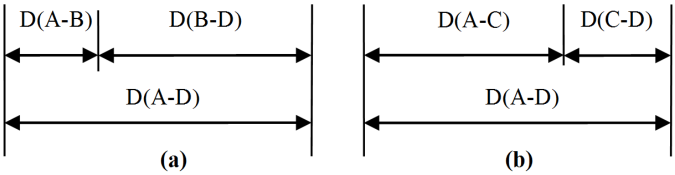

Fig. 5. Design of dimensional chains

and

$$D(C-D)=\begin{bmatrix} 0 & -1 & 1 \end{bmatrix}\begin{bmatrix} D(A-B) \\ D(A-C) \\ D(A-D) \end{bmatrix}=$$

$$=\begin{bmatrix} 0 & -1 & 1 \end{bmatrix}\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 1 & 0 & 1 \end{bmatrix}\begin{bmatrix} AB \\ AC \\ BD \end{bmatrix}=$$

$$=\begin{bmatrix} 1 & -1 & 1 \end{bmatrix}\begin{bmatrix} AB \\ AC \\ BD \end{bmatrix}=AB-AC+BD\,.$$

Finally, when the maximum material model is transformed into mid-tolerance model (using the dimensions from Fig. 3), the design dimension

$$D=\begin{bmatrix} D(A-B) \\ D(A-C) \\ D(A-D) \end{bmatrix} \quad \text{becomes} \quad \begin{bmatrix} 6 \\ 27 \\ 32 \end{bmatrix} \quad \text{from} \quad \begin{bmatrix} 6.12 \\ 29.9 \\ 32.1 \end{bmatrix}.$$

Similarly, the driving parameter

$$X=\begin{bmatrix} AB \\ AC \\ BD \end{bmatrix} \quad \text{becomes} \quad \begin{bmatrix} 6 \\ 27 \\ 26 \end{bmatrix} \quad \text{from} \quad \begin{bmatrix} 6.2 \\ 26.9 \\ 25.98 \end{bmatrix}.$$

The closing link $D(B-D)$ becomes 26 from 25.98 and $D(C-D)$ becomes 5 from 5.2. The mid-tolerance MBD model is shown in Fig. 6.

The results are summarized in Table 3.

Table 3. Generation information table of component mid-tolerance

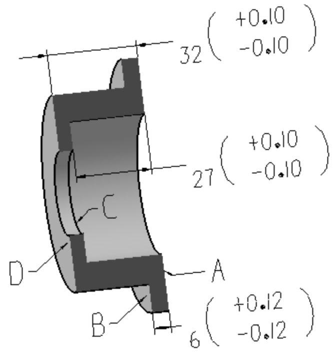

Fig. 6. MBD mid-tolerance model

MD	MMDV	MMTV	MTDV	STV	ID	DP	DV
D(A-B)	6.12	0/-0.24	6	±0.12	D(A-B)	AB	-0.12
					D(B-D)	BD	+0.12
D(A-C)	26.9	+0.2/0	27	±0.1	D(A-C)	AC	+0.1
					D(C-D)	—	-0.1
D(A-D)	32.1	0/-0.2	32	±0.1	D(A-D)	—	-0.1
					D(B-D)	BD	-0.1
					D(C-D)	—	-0.1

Note: MD–marking dimension, MMDV–maximum material dimension value, MMTV–maximum material tolerance value, MTDV–mid-tolerance dimension value, STV–symmetry tolerance value, ID–influenced dimension, DP–driving parameter, DV–dimension variation.

6. Conclusion

Under the MBD technology condition, generation and transformation of MBD mid-tolerance model is the major working content of 3D design process. Through the theoretical analysis, there is the solely definite mathematical relation between one group of engineering dimensions and one group of parameter variables, and also between marking engineering dimensions and non-dimensional engineering dimensions. Any change of engineering dimensions will lead to the change of relevant non-marking engineering dimensions. Therefore, parameter-driving technology may solve the generation and transformation problem of mid-tolerance model. The key part of generation and transformation technology of parameter driving mid-tolerance MBD model is to establish mapping and association relations between marking dimensions with feature driving parameters and feature constraint dimensions. Through developing 3D process design system which integrated 3D modeling system, marking dimension tolerance, driving parameter extraction, dimensional tolerance calculation, and marking dimension and driving parameter association setup are realized. Finally, there are realized automatic generation and transformation working of mid-tolerance MBD model and improving working efficiency and accuracy of data, which provides technological support of integrated technology system of digital design and technique and production based on fully 3D model, which brings a reform to digital manufacturing technology.

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