Study on quality evaluation model in multi-station assembly processes

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Abstract: Based on features of dimension variation propagation in multi-station assembly processes, a new quality evaluation model of assembly processes is established. Firstly, the error source of multi-station assembly system is analyzed, the relationship of dimension variation propagation in multi-station assembly processes is studied and the state equation for variation propagation is constructed too. Then, the feature parameters which influence variation propagation and accumulation in multi-station assembly processes are found to evaluate quality characteristic of the assembly system. Through the derivation of equation on dimension variation propagation, station coefficient matrices which are combined and conversed to determine the max eigenvalue are educed. The max eigenvalue is multiplied by the weight coefficient to establish the quality evaluation model in multi-station assembly processes. Furthermore, assembly variation indexes are proposed to judge of the assembly technology process. Finally, through the practical example, the application of the model and assembly variation indexes are presented.

Key words: multi-station; quality evaluation model; variation propagation; assembly variation indexes

1 Introduction

Assembly is not only an important step in all life cycle of the product, but also the later stage of material integration, fund flow, information flow and error flow, the final formation of product function/performance and quality. The statistics indicates that about 60 % ~ 70 % product quality problems originate from the process of manufacture and assembly[1]. Therefore, as the key aspect which determines the development of enterprises, the process control of product assembly quality has received the unprecedented concerns. W. A. Shewhart invented control chart to monitor each stage quality of product assembly process, but cannot inform the abnormal reason[2]. Zhang Gongxu proposed the cause-selecting control chart and diagnosis theory with two kinds of quality, and made a breakthrough in the Shewhart control chart frame, and divided the product quality into partial quality and total quality to determine and evaluate problematic operation in assembly process[3]. However, the assembly quality control model of the product is based on the statistical process control, the model has obvious disadvantages because it cannot distinguish the relationship between the roots of variation and does not consider the variation correlativity of quality characteristics in dealing with the quality problem caused by dimension variation propagation in the multi-station assembly processes[4,5]. Therefore, the domestic and foreign scholars have investigated the quality problem caused by dimension variation propagation in manufacturing and/or assembly process. In order to deeply research the derivation conversion in manufacturing process, Luo Zhenbi firstly proposed the concept of derivation flow in manufacturing process, established the iteration model of variation propagation, and according to the chaos theory proposed the derivation control principle, the strategy and the method of manufacturing process[6]. Jin Jionghua revealed the propagation, transformation and accumulation of part variations in multi-station assembly processes of sheet metal[5]. Ding and Huang studied optimization of process parameters, process-oriented design, tolerance synthesis and process diagnosis ability analysis on the foundation of Jin's study[7-9]. But the research of quality evaluation based on variation propagation analysis in the multi-station assembly processes has been rarely seen in the literatures and reports. Therefore, according to the relationship of dimension variation propagation in multi-station assembly, the feature parameters which influence variation propagation and accumulation from the processes of assembly system are investigated in this paper, a new model of quality eval-

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uation in multi-station assembly processes is established.

2 Relationship of dimension variation propagation in multi-station assembly processes

Most modern assembly systems are multi-station systems involving a large number of operations performed on multiple assembly stations. Each assembly station introduces derivations that propagate through the system and influence the final product quality. As shown in Fig. 1, product quality derivations $\boldsymbol{X}(n-1)$ accumulated in assembly stations $1, 2, 3, \cdots, n-1$ influence the product quality derivations in assembly station n. In addition, to any assembly station n, new derivations $\boldsymbol{U}(n)$ are introduced and also influence the outgoing product quality $\boldsymbol{X}(n)$. Measurements $\boldsymbol{Y}(n)$ of the part quality can potentially be taken after operations at any station in order to describe the outgoing part quality. In the assembly process, the system random factors $\boldsymbol{V}(n)$ also contributes to the product quality $\boldsymbol{X}(n)$, and thus also appears in the product measured quality characteristics $\boldsymbol{Y}(n)$.

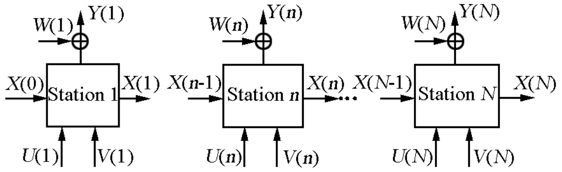


Fig. 1 Dimension variation propagation in multi-station assembly processes

Obviously, dimension variations in multi-station assembly system come from the following four aspects: a. innate manufacture error; b. part derivation caused by fixture position deviation; c. the re-localization accumulated deviation caused by the transform between high and low station; d. in the production process, each kind of random factors like man-power, the equipment, the environment and so on. Under the rigid part and small dimensional derivation assumptions, the steam of variation in multi-station assembly processes can be described in the state-space form[7].

$$\boldsymbol{X}(n) = \boldsymbol{A}(n-1)\boldsymbol{X}(n-1) + \boldsymbol{B}(n)\boldsymbol{U}(n) + \boldsymbol{V}(n) \qquad (1)$$

$$\boldsymbol{Y}(n) = \boldsymbol{C}(n)\boldsymbol{X}(n) + \boldsymbol{W}(n) \qquad (2)$$

Where, $\boldsymbol{X}(n)$ and $\boldsymbol{X}(n-1)$ denote the vectors of all derivations combination on the station n and $n-1$ respectively, $\boldsymbol{V}(n)$ is the stochastic noise factor in the assembly process. $\boldsymbol{A}(n-1) = \boldsymbol{I} + \boldsymbol{R}(n-1)$, known as dynamic matrix of assembly system, characterizes variation change due to part transfer between station n and station $n-1$, matrix $\boldsymbol{I}$ is an identity matrix. The re-localization accumulated derivation caused by the transformation between station n and station $n-1$ is denoted by matrix $\boldsymbol{R}(n-1)$. Matrix $\boldsymbol{B}(n)$ is the input matrix which determines how fixture deviation affects part deviation on station n, based on the geometry of a fixture locating layout. $\boldsymbol{U}(n)$ is the fixture deviation contributed from station n. On station n, k parts are assembled with the subassembly (generally, $k = 1$), the subassembly contains h parts. $\Delta P_h(n)$ is the fixture deviation of subassembly, then input deviation $\boldsymbol{U}(n)$ is

$$\boldsymbol{U}(n) = [\Delta P_h(n) \ \Delta P_{h+1}(n)]^{\mathrm{T}} \qquad (3)$$

$\boldsymbol{Y}(n)$ is the measurement vector obtained on station n, expressed as $\boldsymbol{Y}(n) = [Y_1(n) \cdots Y_r(n) \cdots Y_m(n)]^{\mathrm{T}}$. Matrix $\boldsymbol{C}(n)$ is the observation matrix, $\boldsymbol{V}(n)$, $\boldsymbol{W}(n)$ denote the production noises and the measurement noises respectively.

3 Quality evaluation model of assembly process

The entire assembly process can be regarded as a system and the fixture deviation can be taken as the system input, and the product assembly variation (assembly quality) can be taken as the system output. According to the fixture 4-2-1 localization principle[10], a fixture position deviation vector contain ΔX_{P1}, ΔZ_{P1}, ΔX_{P2} three factors, many fixtures will indicate more fixture deviations. Each component of deviation will cause the deviation change of the part assembled; and it does not always cause the same level of assembly variation in the subassembly or part after many steps of deviation propagation, and component of deviation is a random variable itself. Obviously, it is not comfortable to distinguish assembly quality from the input of fixture position deviation[11]. Assuming input fixture deviation is unknown in the paper, characteristic parameters influencing deviation propagation and accumulation are directly found from the process itself to evaluate quality characteristic of assembly system.

Therefore, the above model is further concluded and analyzed. Assuming part innate manufacture errors are ignored, namely, the system original state is zero, iterative manipulations of Eq.(1) and Eq.(2) yield

$$\begin{bmatrix} y(1) \\ y(2) \\ \vdots \\ y(N) \end{bmatrix} = \begin{bmatrix} \Omega_{1,1} & 0 & \cdots & 0 \\ \Omega_{2,1} & \Omega_{2,2} & \cdots & 0 \\ \vdots & \cdots & \vdots & \vdots \\ \Omega_{N,1} & \Omega_{N,2} & \cdots & \Omega_{N,N} \end{bmatrix} \begin{bmatrix} u(1) \\ u(2) \\ \vdots \\ u(N) \end{bmatrix} + \begin{bmatrix} \Lambda_{1,1} & 0 & \cdots & 0 \\ \Lambda_{2,1} & \Lambda_{2,2} & \cdots & 0 \\ \vdots & \cdots & \vdots & \vdots \\ \Lambda_{N,1} & \Lambda_{N,2} & \cdots & \Lambda_{N,N} \end{bmatrix} \begin{bmatrix} V(1) \\ V(2) \\ \vdots \\ V(N) \end{bmatrix} + \begin{bmatrix} W(1) \\ W(2) \\ \vdots \\ W(N) \end{bmatrix} \qquad (4)$$

Denoting

$$\Omega_{i,j}=\begin{cases}\boldsymbol{C}(i)\Phi(i,i)\boldsymbol{B}(i) & i=j\\ \boldsymbol{C}(i)\Phi(i,j)\boldsymbol{B}(j) & i>j\end{cases}\tag{5}$$

Where, matrix $\Phi(i,j)$, i, $j=1,2,...,N$, is called as state transition matrix, satisfying

$$\Phi(i,j)=\begin{cases}\boldsymbol{A}(i-1)\boldsymbol{A}(i-2)\cdots\boldsymbol{A}(j) & i>j\\ \boldsymbol{I} & i=j\end{cases}\tag{6}$$

$$\Lambda_{i,j}=\boldsymbol{C}(i)\Phi(i,j)\quad i\geqslant j\tag{7}$$

Introducing the notation

$$\begin{aligned}\boldsymbol{Y}&=[y(1)y(2)\cdots y(N)]^{\mathrm{T}}\\ \boldsymbol{U}&=[u(1)u(2)\cdots u(N)]^{\mathrm{T}}\end{aligned}\tag{8}$$

$$\mathrm{M}=\begin{bmatrix}\Omega_{1,1} & 0 & \cdots & 0\\ \Omega_{2,1} & \Omega_{2,2} & \cdots & 0\\ \vdots & \cdots & \ddots & \vdots\\ \Omega_{N,1} & \Omega_{N,2} & \cdots & \Omega_{N,N}\end{bmatrix}\tag{9}$$

$$\gamma=\begin{bmatrix}\Lambda_{1,1} & 0 & \cdots & 0\\ \Lambda_{2,1} & \Lambda_{2,2} & \cdots & 0\\ \vdots & \cdots & \ddots & \vdots\\ \Lambda_{N,1} & \Lambda_{N,2} & \cdots & \Lambda_{N,N}\end{bmatrix}\begin{bmatrix}V(1)\\ V(2)\\ \vdots\\ V(N)\end{bmatrix}+\begin{bmatrix}W(1)\\ W(2)\\ \vdots\\ W(N)\end{bmatrix}\tag{10}$$

γ is taken as the noise term, Eq.(4) becomes a linear model

$$\boldsymbol{Y}=\mathrm{M}\boldsymbol{U}+\gamma\tag{11}$$

The above equation establishes quantitative relationship between product assembly variation $\boldsymbol{Y}$ and the input fixture deviation $\boldsymbol{U}$. The product assembly variation $\boldsymbol{Y}$ is decided by each element of matrix $\boldsymbol{M}$, in the situation that fixture deviation $\boldsymbol{U}$ is certain. Matrix $\boldsymbol{M}$ is composed of system dynamic matrix $\boldsymbol{A}(n)$, input matrix $\boldsymbol{B}(n)$ and observation matrix $\boldsymbol{C}(n)$, reflecting influence degree of each part or subassembly's dimension deviation propagation, accumulation , localization and re-localization in multi-station assembly processes, containing process parameters such as the fixture localization, layout and so on.

In multi-station assembly processes, derivations of some fixture positioning pins on a subassembly appear repeatedly in each station, namely, the position derivation of component are calculated repeatedly. So the same item of the fixture position derivation $\boldsymbol{U}$ can be combined, correspondingly, matrix $\boldsymbol{M}$ can be made the same row combined, then Eq.(11) can be written

$$\boldsymbol{Y}=\boldsymbol{M}\boldsymbol{U}+\gamma\tag{12}$$

Where, matrix $\boldsymbol{M}$ can be decomposed into station coefficient matrix $\boldsymbol{M}_n(n=1,2,\cdots,N)$

$$\boldsymbol{M}=(M_1,\quad M_2,\quad\cdots,\quad M_N)^{\mathrm{T}}\tag{13}$$

Where, $\boldsymbol{M}_n$ is a rectangular matrix, while $\boldsymbol{M}_n^{\mathrm{H}}$ is a conjugate transposed matrix of matrix $\boldsymbol{M}_n$, let $\lambda_{n\max}$ denote as max eigenvalue of matrix $\boldsymbol{M}_n^{\mathrm{H}}\boldsymbol{M}_n$. From Eq.(12), max eigenvalue of station coefficient matrix is variation propagation coefficient of part or subassembly on a station in a certain extent. Then precision request of assembly variation on each station is considered, quality evaluation model in multi-station assembly processes can be expressed as

$$\varphi=\alpha_1\lambda_{1\max}+\alpha_2\lambda_{2\max}+\cdots+\alpha_n\lambda_{n\max}+\cdots\alpha_N\lambda_{N\max}\tag{14}$$

$$\varphi\leqslant k[\varphi]\tag{15}$$

Where, $\lambda_{n\max}$, $(n=1,2,...,N)$ denotes as the max eigenvalue of matrix $\boldsymbol{M}_n^{\mathrm{H}}\boldsymbol{M}_n$ on station n, $\alpha_n(n=1,2,...,N)$, is defined as the weight coefficient associated with variation precision request on station n, the value scope is 0 ~ 1. φ is defined as assembly variation index of product, reflecting the degree of dimension derivation accumulation, coupling and transmission in multi-station assembly processes.

From the above derivation, we can know that while fixture derivation is a certain number, the smaller variation index φ , the lower is variation propagation coefficient of product assembly variation, and the better is product assembly quality. Conversely, if the assembly variation index φ is bigger, product assembly quality gets worse. k is safety margin, generally takes 1.1 ~ 1.3. $[\varphi]$ is the assembly variation index allowed.

4 Example

4.1 Example description

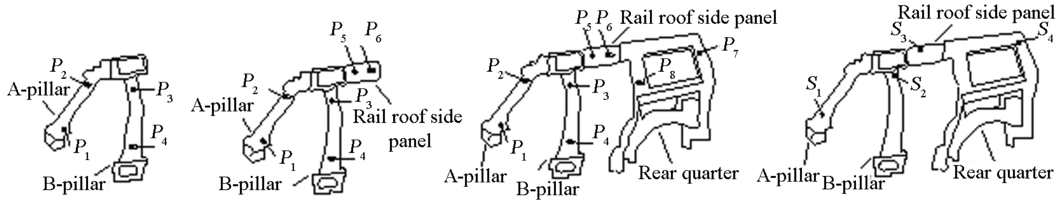
Taking assembly process of the side aperture panel as an example[12], as shown in Fig. 2. Station 1, station 2 and station 3 are the assembly stations, and the examination station is in the station 4. Nominal coordinates of positioning pins $P_k(k=1,2,3,...,8)$ and measuring point $S_r(r=1,2,3,4)$ are shown in Table 1 and Table 2.

Table 1 Coordinates of fixture locators mm

	P_1	P_2	P_3	P_4
x	367.8	667.47	1 301	1 272.73
z	906.05	1 295.35	1 368.89	537.37
	P_5	P_6	P_7	P_8
x	1 407.71	1 770.50	2 941.42	2 120.32
z	1 640.40	1 702.62	1 691.31	1 402.83

Table 2 Coordinates of measurement mm

	S_1	S_2	S_3	S_4
x	271.50	1 289.7	1 604.5	2 884.8
z	905	1 227.5	1 781.8	1 951.5



(a) Station 1 (b) Station 2 (c) Station 3 (d) Station 4

Fig. 2 Assembly process of the side aperture panel

4.2 Calculation of evaluations model parameter

According to Eq. (4) and Eq. (5), various station coefficient matrixes are obtained as follows

$$\boldsymbol{M}_1 = [\,C(1)B(1)\,]$$
$$\boldsymbol{M}_2 = [\,C(2)\Phi(2,1)B(1) \quad C(2)B(2)\,]$$
$$\boldsymbol{M}_3 = [\,C(3)\Phi(3,1)B(1) \quad C(3)\Phi(3,2)B(2) \quad C(3)B(3)\,]$$
$$\begin{aligned}\boldsymbol{M}_4 = [\,&C(4)\Phi(4,1)B(1) \quad C(4)\Phi(4,2)B(2) \\ &C(4)\Phi(4,3)B(3) \quad C(4)B(4)\,]\end{aligned} \tag{16}$$

Denoting

$$\begin{aligned}&\Phi(2,1) = A(1)\\ &\Phi(3,1) = A(2)A(1),\ \Phi(3,2) = A(2)\\ &\Phi(4,1) = A(3)A(2)A(1),\ \Phi(4,2) = A(3)A(2),\\ &\Phi(4,3) = A(3)\end{aligned} \tag{17}$$

The same items of station coefficient matrix $\boldsymbol{M}_1 \sim \boldsymbol{M}_4$ and input matrix $\boldsymbol{U}$, are merged respectively, then the new station coefficient matrix $\boldsymbol{M}_1, \boldsymbol{M}_2, \boldsymbol{M}_3, \boldsymbol{M}_4$ and input matrix $\boldsymbol{U} = [\,\boldsymbol{u}(1) \quad \boldsymbol{u}(2) \quad \boldsymbol{u}(3) \quad \boldsymbol{u}(4)\,]^{\mathrm{T}}$ are obtained, and the max eigenvalue of matrixes $\boldsymbol{M}_1^{\mathrm{H}}\boldsymbol{M}_1$, $\boldsymbol{M}_2^{\mathrm{H}}\boldsymbol{M}_2$, $\boldsymbol{M}_3^{\mathrm{H}}\boldsymbol{M}_3$, $\boldsymbol{M}_4^{\mathrm{H}}\boldsymbol{M}_4$ from station 1 to station 4 are gained, then according to given weight coefficients in Eq. (18), the product assembly variation index φ can be calculated. In the end, according to the allowed variation index $[\,\varphi\,]$, the assembly process quality can be evaluated based on Eq. (19).

$$\varphi = \alpha_1 \boldsymbol{\lambda}_{1\max} + \alpha_2 \boldsymbol{\lambda}_{2\max} + \alpha_3 \boldsymbol{\lambda}_{3\max} + \alpha_4 \boldsymbol{\lambda}_{4\max} \tag{18}$$

$$\varphi \leqslant k[\,\varphi\,] \tag{19}$$

For example, after calculation of the system matrix $\boldsymbol{A}$, $\boldsymbol{B}$, $\boldsymbol{C}$, substituted them into Eq. (16) and Eq. (17), state transition matrix and station coefficient matrix are gained. Considering the limit herein, only list state transition matrix and station coefficient matrix of the fourth station.

$$\Phi(4,1) = \left[\begin{array}{cccccc|ccc|ccc}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\
0 & 0.001\,1 & 1 & 0 & -0.001\,1 & 0.031\,2 & 0 & -0.000\,7 & -0.213\,7 & 0 & -0.000\,6 & 0.468\,5\\
-1 & -0.511\,5 & 0 & 1 & 0.511\,5 & -14.46 & 0 & 0.330\,0 & 98.91 & 0 & 0.264\,1 & -216.85\\
0 & 0.031\,2 & 0 & 0 & -0.031\,2 & 29.15 & 0 & -0.665\,3 & -199.4 & 0 & -0.532\,5 & 437.23\\
0 & 0.001\,1 & 0 & 0 & -0.001\,1 & 1.031\,2 & 0 & -0.000\,7 & -0.213\,7 & 0 & -0.000\,6 & 0.468\,5\\
\hline
 & & & & & & 1 & 0.523\,6 & 156.94 & 0 & 0.4190 & -344.06\\
\multicolumn{6}{c|}{\mathbf{0}^{3\times 6}} & 0 & 0.213\,7 & -235.7 & 0 & -0.629\,3 & 516.74\\
 & & & & & & 0 & -0.000\,7 & 0.786\,3 & 0 & -0.000\,6 & 0.468\,5\\
\hline
 & & & & & & & & & 1 & 0.448\,1 & -367.91\\
\multicolumn{6}{c|}{\mathbf{0}^{3\times 6}} & \multicolumn{3}{c|}{\mathbf{0}^{3\times 3}} & 0 & -0.468\,5 & 1\,205.81\\
 & & & & & & & & & 0 & -0.000\,6 & 1.468\,5
\end{array}\right]_{12\times 12}$$

$$\Phi[4,2]=\left[\begin{array}{ccc|c|ccc|ccc}
0 & 0 & 0 & & 0 & 0 & 0 & 0 & 0 & 0\\
0 & 0 & 0 & \mathbf{0}^{3\times 3} & 0 & 0 & 0 & 0 & 0 & 0\\
0 & 0.000\,7 & 1 & & 0 & -0.000\,7 & -0.213\,7 & 0 & -0.000\,6 & 0.468\,5\\
\hline
-1 & -0.330\,0 & 0 & & 0 & 0.330\,0 & 98.91 & 0 & 0.264\,1 & -216.85\\
0 & -0.334\,7 & 0 & \boldsymbol{I}^{3\times 3} & 0 & -0.665\,3 & -199.4 & 0 & -0.532\,5 & 437.23\\
0 & 0.000\,7 & 0 & & 0 & -0.000\,7 & -0.213\,7 & 0 & -0.000\,6 & 0.468\,5\\
\hline
-1 & -0.523\,6 & 0 & & 1 & 0.523\,6 & 156.94 & 0 & 0.419\,0 & -344.06\\
0 & -0.213\,7 & 0 & \mathbf{0}^{3\times 3} & 0 & 0.213\,7 & -235.7 & 0 & -0.629\,3 & 516.74\\
0 & 0.000\,7 & 0 & & 0 & -0.000\,7 & 0.786\,3 & 0 & -0.000\,6 & 0.468\,5\\
\hline
 & & & & & & & 1 & 0.448\,1 & -367.9\,1\\
 & \mathbf{0}^{3\times 3} & & \mathbf{0}^{3\times 3} & & \mathbf{0}^{3\times 3} & & 0 & -0.468\,5 & 1\,205.81\\
 & & & & & & & 0 & -0.000\,6 & 1.468\,5
\end{array}\right]_{12\times 12}$$

$$\Phi(4,3)=\left[\begin{array}{ccc|c|ccc}
0 & 0 & 0 & & 0 & 0 & 0\\
0 & 0 & 0 & \mathbf{0}^{3\times 6} & 0 & 0 & 0\\
0 & 0.000\,6 & 1 & & 0 & -0.000\,6 & 0.468\,5\\
\hline
-1 & -0.264\,1 & 0 & & 0 & 0.264\,1 & -216.85\\
0 & -0.467\,5 & 0 & & 0 & -0.532\,5 & 437.23\\
0 & 0.000\,6 & 0 & \boldsymbol{I}^{6\times 6} & 0 & -0.000\,6 & 0.468\,5\\
-1 & -0.419\,0 & 0 & & 0 & 0.419\,0 & -344.06\\
0 & -0.370\,7 & 0 & & 0 & -0.629\,3 & 516.74\\
0 & 0.000\,6 & 0 & & 0 & -0.000\,6 & 0.468\,5\\
\hline
-1 & -0.448\,1 & 0 & & 1 & 0.448\,1 & -367.91\\
0 & 0.468\,5 & 0 & \mathbf{0}^{3\times 6} & 0 & -0.468\,5 & 1\,205.81\\
0 & 0.000\,6 & 0 & & 0 & -0.000\,6 & 1.468\,5
\end{array}\right]_{12\times 12}$$

$$\boldsymbol{M}_4=\begin{bmatrix}
1 & -0.034 & 0.003\,4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\
0 & 1.317\,0 & -0.317\,8 & 0 & -0.000\,4 & 0.000\,5 & 0 & -0.000\,5 & 0.000\,5 & 0 & 0.003\,6 & -0.003\,7\\
0 & -0.013\,6 & 0 & 1 & 5.005\,5 & -5.005\,5 & 0 & 0.004\,3 & -0.004\,3 & 0 & -0.001\,5 & -0.012\,2\\
0 & -0.027\,4 & 0 & 0 & 0.600\,8 & 0.399\,3 & 0 & -0.007\,3 & 0.007\,3 & 0 & -0.007\,4 & -1.085\,0\\
0 & 0.021\,6 & 0 & 0 & 0 & 0 & 1 & 0.470\,7 & -0.470\,7 & 0 & 0.011\,5 & -0.033\,1\\
0 & -0.032\,4 & 0 & 0 & 0 & 0 & 0 & 0.550\,7 & 0.449\,3 & 0 & -0.014\,3 & 0.045\,7\\
0 & 0.023\,1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -0.295\,8 & 0.272\,7\\
0 & -0.075\,7 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1.044\,3 & 0.031\,5
\end{bmatrix}_{8\times 12}$$

According to the assembly accuracy requirement of four stations in the side aperture panel, taken 0.25, 0.25, 0.4, 0.1 as its weight coefficients respectively. According to the above result, in Eq.(14), the assembly variation index of the side aperture panel can be obtained as

$$\varphi=\alpha_1\lambda_{1\max}+\alpha_2\lambda_{2\max}+\alpha_3\lambda_{3\max}+\alpha_4\lambda_{4\max}=5.113\,16$$

Obviously, when the weight coefficient is different, the assembly variation index of the side aperture panel is different too, which can be determined by construction feature and process technology of the side aperture panel. The assembly quality of the four stations can be judged as follows: a. according to assembly experience determine the assembly variation index allowed; b. by resolving the assembly variation index under the different assembly technique. If assembly variation index is smaller, the assembly process quality is superior.

5 Conclusions

The relationship of dimension variation propagation in multi-station assembly processes is studied and the state equation for variation propagation is constructed too. Then, the feature parameters which influence variation propagation and accumulation from the processes are found to evaluate assembly quality characteristic of the system. By the derivation of dimension variation propagation, station coefficient matrices which are combined and conversed to determine the max eigenvalue are educed. The max eigenvalue is multiplied by the variation precision factor to establish the new quality evaluation model of assembly processes. Furthermore, assembly variation index is proposed to evaluate the assembly technology process. Finally, with the assembly process of the side aperture panel, the application method of the model and assembly variation indexes are presented.

The proposed model of quality evaluation for assembly process lays the foundation for the following researches: a. quality evaluation and technology flow optimize. The model provides quantitative evaluation for process quality of multi-station assembly, and also can appraisal the multi-station assembly technique flow. For example, the assembly variation index is taken as judgment factor to optimize and select assemble sequence, enhancing the assembly quality characteristic of product. b. fixture localize design and optimize. The quality evaluation model provided the quantitative relationship between the fixture position derivation and the part derivation, the minimum of assembly variation index is taken as the objective function to design and optimization the fixture localization. c. quality monitor and diagnosis of assembly process. Based on the quality evaluation model of assembly process, many well-developed algorithms in control system can be directly applied to process monitoring and control of assembly process. For example, the sudden change inspection techniques for fixture failure detection (e.g. broken or missing locating pins). The system identify technology to model assembly process quality provides the evaluation of process and fixture design under production environment.

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