Fixture Locating Precision Pre-Analysis for One-plane-dual-pins fixture System

Liu Wei-dong*, Guo Jinhui

College of Automatic Science and Engineering, South China University of Technology, Guangzhou, 510640

aulwd@scut.edu.cn

Abstract. Type two assembly is mainly fixed by additional fixture but not its own features, and the one-plane-dual-pins fixture system is commonly used for type two assembly assurance; hence, the locating pre-analysis for one-plane-dual-pins fixture system is introduced. The locating variation in one-plane-dual-pins fixture system leads to the gesture displacement of the workpiece in space. Variation source that affects the fixture locating precision mainly includes the fixture locating error and the fabrication error of the fitting holes. While the fixture error and fabrication error of the fitting holes are confirmed, the calculation for the fixture locating error of assembled workpiece is introduced. The fixture locating error simulation is further researched, and one example for fixture locating error propagation is illustrated.

1. Introduction

There are generally two types of assembly during the assembly process: 1) the assembly between two parts or components by fitting operation, where the latter part or component is located according to the first part basis without specific fixture; 2) the assembly between two parts or components by riveting or welding, and each parts or components is located by specific fixture individually. The typical specific fixture layout for pre-locating the assembled workpiece is one-plane-dual-pins layout system. One-plane is usually the large surface for fixing the part, and one of the dual-pins is cylindrical pin, the other pin is the prism pin.

Pre-locating analysis of one-plane-dual-pins layout system is significant for ensuring the assembly accuracy of type two assembly. Wu et al. [1] introduced models for different types of fixture layout system based on the mechanism mapping, and it provides the foundation model for the analysis of locating accuracy. Luo et al. [2] studied the locating problem of any space surface, and analyzed the positioning problem by distance function. Liu et al [3] established a positioning mapping model between the element fixture and the workpiece to minimize the locating error. Tsai et al. [4] proposed a matrix analysis method for the positioning design of prismatic parts.

For actual practice application, the locating accuracy problem of one-plane-dual-pins layout system is discussed in this paper. Size error of the locating pins and holes are considered, and pre-locating analysis of one-plane-dual-pins layout system is introduced.

2. Error source of one-plane-dual-pins fixture system

For type two assembly, the one-plane-dual-pins fixture system is shown in Fig. 1. The locating basis is Oxyz, the cylindrical pin is P$_1$, and the prism pin is P$_2$. The workpiece can translate along the positioning groove that is α angle with x-axis.

The factors that affecting the locating error of one-plane-dual-pins fixture system include:

(1) The locating error of P1 and P_2: ΔX_{P_1}, ΔZ_{P_1}, ΔX_{P_2} and ΔZ_{P_2}.

(2) The locating error of the fitting holes of workpiece. The hole fitting with P_1 is Y_1, and the hole fitting with P_2 is Y_2; the locating error of the fitting holes of workpiece are: ΔX_{Y_1}, ΔZ_{Y_1}, ΔX_{Y_2} and ΔZ_{Y_2}.

(3) While the assembled workpieces are more than three, the repeated locating error of the part is included.
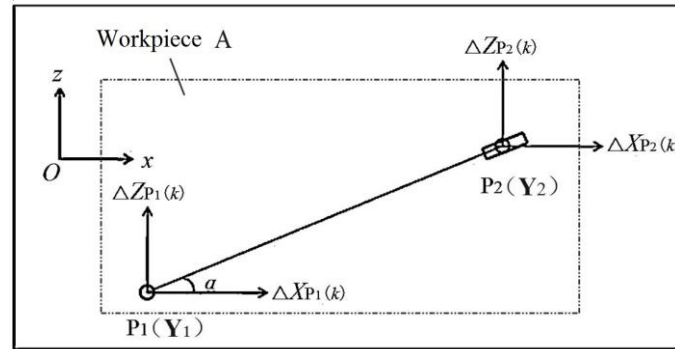
Figure 1. fixture locating of the part in x-z plane

3 Fixture error and locating hole error

3.1 Assembly displacement caused by fixture error
Suppose that the fixture error in process k caused by P_1 and P_2 can be recorded as:

$$\Delta P(k) = [\Delta X_{P_1}(k), \Delta Z_{P_1}(k), \Delta X_{P_2}(k), \Delta Z_{P_2}(k)]^{\mathrm{T}} \tag{1}$$

According to reference [5], the locating error of workpiece A caused by the fixture error of P_1 and P_2 in process k is:

$$X_{\mathrm{A}}^{\mathrm{L}}(k) = M_{\mathrm{AP_1}} Q_{\mathrm{P_1P_2}}(k) \Delta P(k) \tag{2}$$

Where $Q_{\mathrm{P_1P_2}}(k)$ is

$$Q_{\mathrm{P_1P_2}}(k) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ \dfrac{\sin\alpha}{L^F} & \dfrac{-\cos\alpha}{L^F} & \dfrac{-\sin\alpha}{L^F} & \dfrac{\cos\alpha}{L^F} \end{bmatrix} \tag{3}$$

$$M_{\mathrm{AP_1}} = \begin{bmatrix} 1 & 0 & -L_Z(\mathrm{A},\mathrm{P_1}) \\ 0 & 1 & -L_X(\mathrm{A},\mathrm{P_1}) \\ 0 & 0 & 1 \end{bmatrix} \tag{4}$$

Where L^{F} is the distance between P_1 and P_2; $L_Z(\mathrm{A},\mathrm{P_1}) = Z_{P_1} - Z_{\mathrm{A}}$, $L_X(\mathrm{A},\mathrm{P_1}) = X_{P_1} - X_{\mathrm{A}}$, which are the distances along x and z directions between the centroid point of workpiece and P_1.
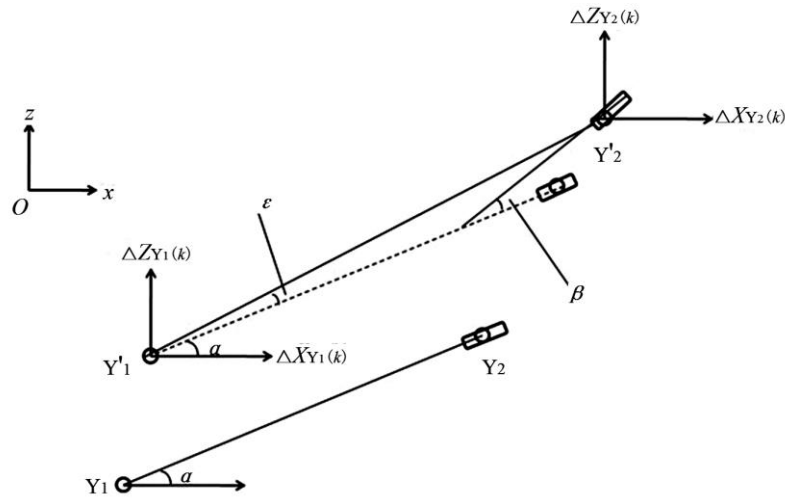
3.2 Assembly displacement caused by error of the fitting hole and groove
The locating accuracy also affected by the fabricating error of the fitting hole Y_1 and the fitting groove Y_2. As shown in Fig. 2, suppose that Y_1, Y_2 are the ideal positions of fitting hole and groove, and Y_1', Y_2' are actual positions of fitting hole and groove, the rotation offset of the workpiece is ε.
Suppose that the fabricating error of the fitting hole and groove in process k caused by Y_1 and Y_2 can be recorded as:
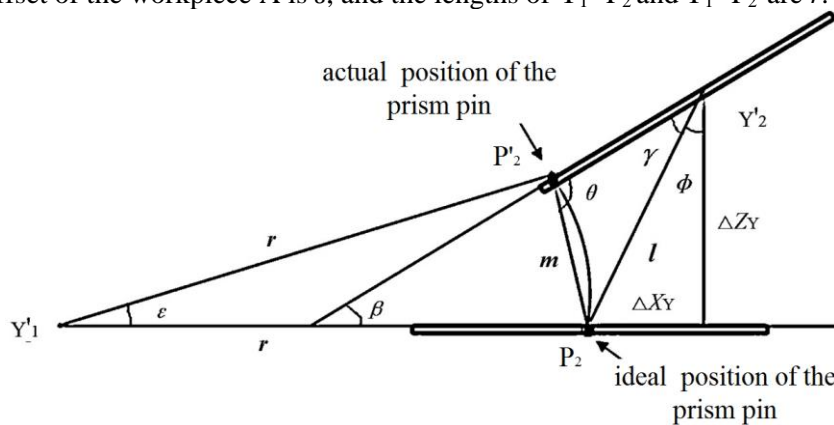
$$\Delta Y = [\Delta X_{Y_1}(k), \Delta Z_{Y_1}(k), \Delta X_{Y_2}(k), \Delta Z_{Y_2}(k), \beta(k)]^{\mathrm{T}} \tag{5}$$

Where $\Delta X_{Y_1}(k)$, $\Delta Z_{Y_1}(k)$ are translation displacement along the x-axis and z-axis direction caused by Y_1, and $\Delta X_{Y_2}(k)$, $\Delta Z_{Y_2}(k)$ are translation displacement along the x-axis and z-axis direction caused by Y_2, and $\beta(k)$ is the rotation displacement of the fitting groove.

Figure 2. locating accuracy affected by the fabricating error of the fitting hole and groove

The locating error of workpiece A caused by the fabricating error of the fitting groove Y_2 in process k is shown in Fig.3. The ideal position of the prism pin is P_2 and the actual position of the prism pin is P_2'. The rotation offset of the workpiece A is ε, and the lengths of $Y_1' P_2$ and $Y_1' P_2'$ are r.

Figure 3. locating error of workpiece A caused by the fabricating error of fitting groove Y_2

As shown in Fig. 3, the displacement of Y_2' referring to Y_1' in the x-axis direction is $\Delta X_Y(k) = \Delta X_{Y_1}(k) - \Delta X_{Y_2}(k)$, in the z-axis direction is $\Delta Z_Y(k) = \Delta Z_{Y_1}(k) - \Delta Z_{Y_2}(k)$. In addition, the following six equations exist:

$$l = \sqrt{\left(\Delta X_Y\right)^2 + \left(\Delta Z_Y\right)^2} \tag{6}$$

$$\Phi = \arctan \frac{\Delta X_Y}{\Delta Z_Y} \tag{7}$$

$$\beta + \gamma + \Phi = \frac{\pi}{2} \tag{8}$$

$$\frac{m}{\sin \gamma} = \frac{l}{\sin \theta} \tag{9}$$

$$\theta = \beta + \frac{\pi - \varepsilon}{2} \tag{10}$$

$$m \approx 2r\sin\frac{\varepsilon}{2} \tag{11}$$

Solving the equations, the rotation offset of the workpiece is ε:

$$\varepsilon = \beta + \arcsin\left[\frac{\sin(\frac{\pi}{2} - \beta - \arctan\frac{\Delta X_Y}{\Delta Z_Y})\sqrt{(\Delta X_Y)^2 + (\Delta Z_Y)^2}}{r} - \sin\beta\right] \tag{12}$$

The locating error of workpiece A caused by the fitting hole Y_1 in process k is:

$$X_{Y_1}^{L2}(k) = \left[\Delta X_{Y_1}, \Delta Z_{Y_1}, \varepsilon\right]^{\mathrm{T}} \tag{13}$$

The locating error of workpiece A caused by the fitting groove Y_2 in process k is:

$$X_A^{L2}(k) = M_{AY_1}[-\Delta X_{Y_1} - \Delta Z_{Y_1} - \varepsilon]^{\mathrm{T}} \tag{14}$$

According to Eq. (12), the ΔX_Y-ε, ΔZ_Y-ε simulation are particularly introduced with $\beta = 5°$, $15°$, $30°$, $60°$ and $90°$.

(1) If $\Delta Z_Y = 0.1$cm, $r = 50$cm, the ΔX_Y-ε function curve is shown in Fig.4. As shown in Fig. 4, the ΔX_Y-ε function curve is distributed in the first and third quadrant. The larger value of ΔX_Y, can result in the smaller value of ε; while $\Delta X_Y < -0.0001$, the larger value of β, can result in the larger value of ε; while $\Delta X_Y > -0.0001$, the larger the value of β, can result in the smaller value of ε.
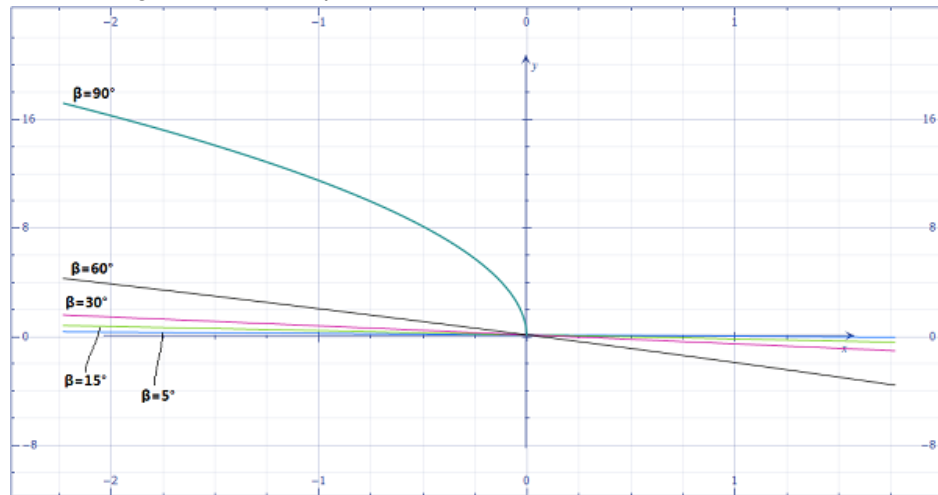
Figure 4. ΔX_Y - ε function curve

(2) If $\Delta X_Y = 0.1$cm, $r = 50$cm, the ΔZ_Y-ε function curve is shown in Fig.5. As shown in Fig. 5, the ΔZ_Y-ε function curve is distributed in the first and second quadrant. In the second quadrant, the larger value of ΔX_Y, can result in the smaller value of ε; while $\Delta X_Y < -3.161$, the larger value of β, can result in the smaller value of ε; while $\Delta X_Y > -3.161$, the larger the value of β, can result in the larger value of ε. In the first quadrant, the larger value of ΔX_Y, can result in the larger value of ε; the larger value of β, can result in the larger value of ε.
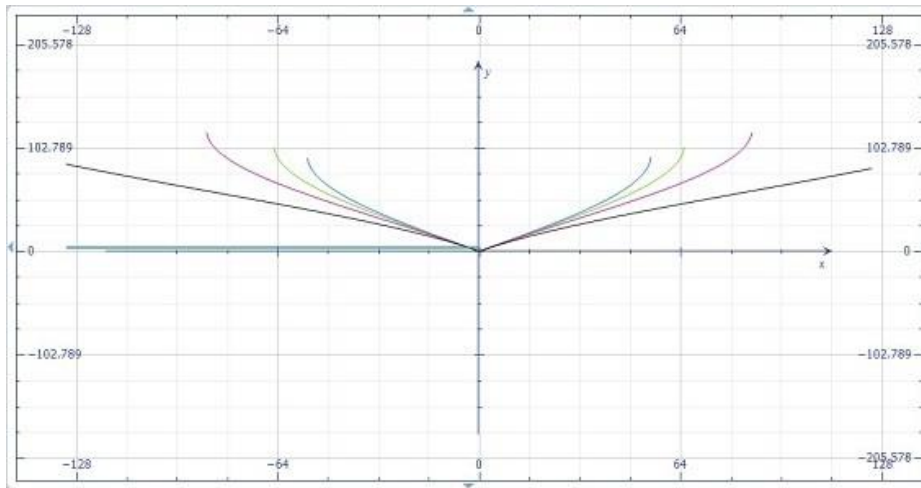
Figure 5. ΔZ_Y - ε function curve

4. Case Study

An assembly with three workpieces is illustrated as an example to verify the calculation of locating accuracy. Fig. 6 is the individual station for this assembly; the dotted line shows the nominal position of parts, and the solid line shows the actual position of parts.

Suppose that the two positioning pins of part one are P_1, P_2; respectively, and the positioning groove are Y_1, Y_2. The two positioning pins of part two are P_3, P_4, and the positioning groove are Y_3, Y_4. Assuming that (1) the fixture error of part one is $\Delta P_{11} = [1,1,1,2]$, the angle α_1 referring to the x-axis is 60 °, and the distance between the two pins is $L^{F1} = 500$mm. (2) the locating error of part one is $\Delta Y_1 = [1,2,1,2, \frac{\pi}{180}]$, the distance between the fitting hole and fitting groove is $R_1 = 500$mm. (3) the fixture error of part two is $\Delta P_{12} = [1,1,2,1]$, the angle α_2 referring to the x-axis is 60 °, and the distance between the two pins is L^{F2} = 500mm. (4) the locating error of part two is $\Delta Y_2 = [2,1,2,1, \frac{\pi}{180}]$, the distance between the fitting hole and fitting groove is $R_2 = 500$mm.
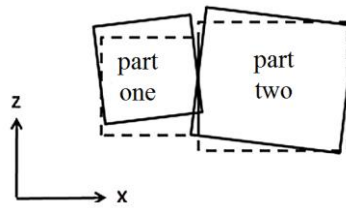
Figure 6. Schematic diagram of assembly within individual station

Within the assembly, suppose that:

$$M_{A_1P_1} = M_{A_2P_3} = M_{A_1Y_1} = M_{A_2Y_3} = \begin{bmatrix} 1 & 0 & 1 \\ 0 & 1 & -1 \\ 0 & 0 & 1 \end{bmatrix}$$

The locating error of part one caused by the fixture error is $X_{A_1}^{L_1}(1) = [1.00002, 0.99998, 0.00002]^T$, and the locating error of part two caused by the fixture error is $X_{A_2}^{L_1}(1) = [0.99997, 1.00003, -0.00003]^T$. The locating error of part one caused by the fabricating error of fitting hole and groove is $X_{A_1}^{L_2}(1) = [-1.00197, -1.99803, -0.00197]^T$, and the locating error of part two caused by the fabricating error of fitting hole and groove is $X_{A_2}^{L_2}(1) = [-2.00197, -0.99803, -0.00197]^T$. According to equation reference [5], the variable flow of station one is:

$$X(1) = \begin{bmatrix} -0.00195 & -0.99805 & -0.00199 \\ -1.002 & 0.002 & 0.002 \\ 0 & 0 & 1 \end{bmatrix}$$

Similarly, for individual station two, suppose that the subassembly after assembly station one is recorded as {1,2}; the two positioning pins of subassembly {1,2} are P_1, P_2; respectively, and the positioning groove are Y_1,Y_2. The two positioning pins of part three are P_5, P_6, and the positioning groove are Y_5,Y_6. Assuming that:

(1) the repeated locating error of part one is $X_{A1}^{L_2}(2) = [0.00195, 0.99805, 0.00199]^T$, the repeated locating error of part two is $X_{A2}^{L_2}(2) = [0.2185, 0.00305, 0.00199]^T$;

(2) the fixture error of subassembly {1,2} is $\Delta P_{21} = [1,1,1,2]$, the angle α_1 referring to the x-axis is 60°, and the distance between the two pins is $L^{F1} = 500$mm; the locating error of part one is $\Delta Y_1 = [1,2,1,2, \frac{\pi}{180}]$, the distance between the fitting hole and fitting groove is $R_1 = 500$mm.

(3) the fixture error of part three is $\Delta P_{23} = [0.8, 0.3, 0.6, 0.4]$, the angle α_2 referring to the x-axis is 60°, and the distance between the two pins is $L^{F3} = 500$mm. (4) the locating error of part three is $\Delta Y_3 = [0.9, 1.1, 1, 2, \frac{\pi}{180}]$, the distance between the fitting hole and fitting groove is $R_3 = 500$mm.

Within the assembly, suppose that:

$$M_{A3P5} = M_{A3Y5} = \begin{bmatrix} 1 & 0 & 1 \\ 0 & 1 & -1 \\ 0 & 0 & 1 \end{bmatrix}$$

The locating error of part one caused by the fixture error is $X_{A1}^{L_1}(2) = [1.00002, 0.49998, 0.00002]^T$; the locating error of part two caused by the fixture error is $X_{A2}^{L_1}(2) = [1.00028, 0.48823, 0.00002]^T$, and the locating error of part two caused by the fixture error is $X_{A3}^{L_1}(2) = [0.80001, 0.29999, 0.00001]^T$. The locating error of part one caused by the fabricating error of fitting hole and groove is $X_{A1}^{L_2}(2) = [-1.00197, -1.99803, -0.00197]^T$, the locating error of part two caused by the fabricating error of fitting hole and groove is $X_{A2}^{L_2}(2) = [-1.02166, -1.01504, -0.00197]^T$, and the locating error of part three caused by the fabricating error of fitting hole and groove is $X_{A3}^{L_2}(2) = [-0.93291, -1.06709, -0.03291]^T$ According to equation reference [5], the variable flow of station two is:

$$X(2) = \begin{bmatrix} -0.00195 & -0.99805 & -0.00195 \\ -0.80488 & -0.50376 & 0.00125 \\ -0.1329 & -0.7671 & -0.0039 \end{bmatrix}$$

5. Summary

The locating variation in one-plane-dual-pins fixture system is mainly caused by the fixture error of the positioning pin, and is caused by the fabricating error of fitting hole and groove of each part. For type two assembly, locating accuracy pre-analysis of one-plane-dual-pins fixture system is important for pre-analysis of the final functional assembly requirement. In this paper, the locating and direction error of two-pin positioning part are analyzed; the accuracy of the parts with fabricating error of fitting hole and groove are further calculated. Considering the assembly with three parts, an example is introduced for calculation verification.

6. References

[1]　WU Yuguang, ZHANG Genyuan, LI Chunguang. Approach to automated modeling of fixture location errors analysis [J]. Journal of Mechanical Engineering, 2012, 48(5): 172-179 (in Chinese)

[2]　LUO Chen, ZHU Limin, DING Han, et al. Statistical characteristic and relative error among fixturing analysis models [J]. Journal of Mechanical Engineering, 2013,45(9): 110-115 (in Chinese) [3] LIU Wenlin, XIONG Caihua. Model of locating error for fixtures [J]. Journal of Huazhong University of Science and Technology: Nature Science, 2003, 31 (7): 72-74 (in Chinese).

[3]　LIU Wenlin, XIONG Caihua. Model of locating error for fixtures [J]. Journal of Huazhong University of Science and Technology: Nature Science, 2003, 31 (7): 72-74 (in Chinese).

[4]　TSAI Y.H , LU S.S. Localization accuracy matrix analysis for localization accuracy consideration in 2D precision fixture system [C] //Proceedings of 2007 Mediterranean Conference on Control and Automation, doi: 10. 1109/ MED. 2007. 4433966.

[5]　TIAN Zhaoqing, LAI Xinmin, LIN Zhongqin. State space model of variaitions stream propagation in multistation assembly processes of sheet metal [J]. Journal of Mechanical Engineering, 2007, 43(2):202-209 (in Chinese)

7. Acknowledgement