Research on locating method without clearance of one plane and two pins

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Abstract: In the mass production of box and monoblock parts, due to the clearance between the traditional location of one plane and two pins, subsequently the complete unification of datums of each process cannot be reached, which easily causes the problem of unstable product quality. A new clearance-free locating method by using two elastic multi-tooth cylindrical pins instead of traditional cylindrical pins and diamond pins is proposed. The elastic interval of the teeth of the locating pin is searched by the least square method, then tolerance zone of the center distance of the locating hole only satisfies to the elastic interval. The clearance between pin and hole is eliminated through self-adaptive fitting relied the resilience of elastic teeth of locating pin, consequently the real unification of benchmarks of each process is realized. Ultimately, the validity of the proposed clearance-free locating method is verified by numerical simulation.

1. Introduction
With the rapid development of manufacturing industry, high-precision manufacturing has become the focus of global attention and competition. Although great progress has been made in Chinese manufacturing industry in recent years, the manufacturing of high-precision parts has always been the bottleneck of Chinese high-end machining and manufacturing technology. The high accuracy locating techniques and methods are necessarily required in order to high accuracy workpieces. However, the locating method of one plane and two pins is still one of the important locating schemes for machining the core parts of mechanical products such as engine cylinder, large shell and bracket. In the mass machining of parts with complex and high accuracy requirements, the locating holes and locating pin clearances are arbitrary when each cylinder is being located, ultimately the machining accuracy of engine cylinder can be affected greatly. Besides, the surface characteristics of the cylinder are extremely complex, and it is impossible that all the processes is completed in one clamp locating, therefore the repeated locating of the cylinder is inevitable. In the traditional one-plane two-pin locating method, the clearance will occur when each pin is cooperated with the workpiece. The error value of each pin is non-fixed and random, thus the locating datum is not uniform in the repeated locating process.

Location error is one of the main factors affecting the machining accuracy of engine cylinder and shell parts. The research on the location error of one plane and two pins has been a hot topic widely concerned by scholars. A calculating method of the center deviation of two locating pins was proposed by Yu Shiwei[1], the location error was improved through adjusting the copulation accuracy of locating pins, and the allowable center distance deviation of locating holes can be larger concurrently.
A novel method for calculating center distance tolerance was devised by Wang Weimo [2], which was beneficial to the standardization of double pins. However, this method is only suitable for locating occasion with smaller center distance tolerance of two holes. The optimal geometric tolerance for rigid parts with assembly requirements was designed by A. Saravanan and C. Balamurugan [3], eventually the optimal assembly tolerance was analyzed through one plane and two holes locating parts as an example. The design formula of one plane and two holes locating was derived by Zhang et al. [4] through probability theory, then the locating accuracy was improved significantly compared with the extreme value method. The geometric error model was established by Lucheng under multi-tolerance coupling [5]. The actual machining error was simulated by Monte Carlo method, ultimately the actual variation zones of each error component of geometric elements were obtained. In addition, the explicit functional relationship between the actual variation zones and tolerances of each error component of geometric elements were established by response surface method [6]. The fixtures of the elastic core-expanding shaft and the telescopic spring taper pin were devised by Dong [7], then the locating accuracy of raw hole was improved, consequently the requirements of the fixture accuracy was effectively satisfied in workparts precise locating process.

In aforementioned references, the locating pins served in the locating process can be roughly divided into rigid pins and flexible pins. Rigid pin refers to the traditional one-plane two-pin, i.e., one cylindrical pin and the other diamond pin. When the traditional one-plane two-pin is devoted in each locating process, the machining accuracy of the workpiece was seriously affected owing to the non-fixed clearance between the pin and hole. While flexible pin denotes a thin-walled positioning pin with plastic-liquid inside, then the clearance between the locating pin and hole was reduced to large extent consequently the machining accuracy of the workpiece was improved. However, the deformation of the plastic-liquid locating pin is uneven and difficult to control. In addition, the cost of the plastic-liquid locating pin is higher and its service life is shorter. In view of the above problems, a novel one-plane two-cylinder pin is adopted in this paper based on the previous research results. The closest fit between the pin and the hole is reached through the resilient force of the elastic flaps of the locating pin without considering the minimum clearance error and rotation error of the pin and hole of the traditional one-plane two pins. The real unification of locating datum is realized and the machining accuracy of workpiece is significantly improved concurrently.

2. Over-constraint analysis of one plane and two pins

Pin-hole fit is also known a kind of shaft-hole fit, and pin-hole fit is widely devoted to parts locating, mechanical transmission and other fields. Locating accuracy plays an indispensable role in the quality and functions of mechanical products. When the workpiece is located with the traditional one-side two-pin, owing to manufacturing error of the center distance of the two positioning holes on the workpiece, then the sum of the tolerances of the two located holes \( \pm \frac{\varepsilon_1}{2} \) of the machined workpiece and the two pin holes \( \pm \frac{\varepsilon_2}{2} \) of the fixture are not matched (larger or smaller). Eventually some workpieces will not be properly clamped located, such as illustrated in Figure 1.

![Figure 1](image_url)

**Figure 1** One plane and two pins with assembly interference

In order to avoid over-constraint the phenomenon of one plane and two pins, one of the two pins is served as the locating datum, and the locating pins the center distance errors of the two locating holes and the pins were compensated. Because the alignment direction of two pins hole is over-positioned, and it can be avoided by reducing the diameter of the alignment direction of the two locating holes. Over-constraint is allowed in mechanical manufactures, and it is increasingly adopted in machinery widely. So as to make rational use of the over-constraint and the workpieces are smoothly loaded and unloaded concurrently, thus the locating pin shown in Figure 2 is designed.
Figure 2 Clearance-free locating of one plane and two pins

As illustrated in Fig. 2, the structure of teeth flaps is adopted by two pins, in which each locating pin is composed of upper and lower parts, and loaded into the clamp body and workpiece respectively. Each tooth is spring steel and has certain elasticity. When the workpiece is clamped, the clearance fit of the locating pin and hole is achieved owing to the elastic tooth. When clamp is completed, the locating teeth and the inner wall of the positioning hole can be uniformly fitted due to the resilience force of the elastic teeth, eventually the relative clearance-free locating is reached. In addition, the adduction form is taken by the elastic teeth on the top of the locating pin, therefore the elastic teeth are effectively protected and play a guiding role in fit of pin and hole.

3. The calculation model of elastic zone of locating teeth

The two locating holes on the bottom of a four-cylinder engine block in a tractor factory are served as an example, then the elastic variation zone of the minimum locating pin teeth that assimilated the center distance tolerance of the locating holes is calculated. The designed dimension of the locating holes is 400±0.03mm.

The datum axis of cylindrical pin surface is determined according to the principle of least square method, then two coaxial ideal cylindrical surfaces are made based upon datum axis. All actual measured cylinder pin surfaces are contained in the ideal cylinder zone, consequently the deviation between the two ideal cylinder surfaces is the error variation of the locating pin cylinder surface. The coordinate system of the locating pin is established such as illustrated in Figure 3, the equidistant cross-sections are sampled along the pin axis direction. Thus data points reflected the profile of the locating pin is collected on each equidistant cross-section. The section centered on \( o_i \) denotes the \( i \)-th equidistant cross-section of the locating pin, the point \( p_{ij} \) means any point in the elastic zone on the section of the locating pin. The colored annulus is the elastic zone of the locating pin. Suppose the coordinates of data points in the cylinder pin coordinate system are set as \( p_{ij} (x_{ij}, y_{ij}, z_{ij}) (i = 1, 2, ..., n; j = 1, 2...s) \), the larger the values of \( n, s \), the more precise the variation of the pin profile will be, on the contrary, the more blurred.

Figure 3 The elastic zone of the teeth of the locating pin
Assuming that the axis of the least square cylinder surface of the locating pin actually measured is \( D \), and the starting point of the axis is \( O_0 (a, b, 0) \), a set of directional numbers of the axis can be expressed \( u, v, w \), eventually the equation of \( D \) is derived.

\[
\frac{x-a}{u} = \frac{y-b}{v} = \frac{z}{w} \tag{1}
\]

Simplified equation (1).

\[
\begin{align*}
x &= a + \frac{u}{w} z \\
y &= b + \frac{v}{w} z
\end{align*} \tag{2}
\]

Let \( s = u / w, t = v / w \), then the equation of \( D \) axis is transformed as follow.

\[
\begin{align*}
x &= a + sz \\
y &= b + tz
\end{align*} \tag{3}
\]

The direction number \( s, t, 1 \) of \( D \) can be obtained from (3). The distances between the data points collected and the \( D \) axis are \( d_{ij} \), the cylinder radius of the least squares locating pin is \( R \). and five unknowns are \( a, b, s, t, R \) respectively.

In the \( i \)-th sampling cross-section of the locating pin, suppose \( o_i (a_i, b_i, c_i) \) denote the intersection points of the center axis \( D \) and the \( i \)-th equidistant cross-section. The distance equation from point to line is as follows:

\[
(p_y - o_y) \times e = |e| \tag{4}
\]

Where \( p_y = [x_y, y_y, z_y]^T \), \( o_y = [a, b, 0]^T \), \( e = [s, t, 1]^T \), then substituted into equation (4).

\[
d_y = \left| \frac{(p_y - o_y) \times e}{|e|} \right| \tag{5}
\]

\[
H(a, b, s, t, R) = \sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{k=1}^{n} \sum_{l=1}^{n} \xi_{ijl}^2
\]

\[
= \sum_{i=1}^{n} \sum_{j=1}^{n} \frac{\left[ x_y - a - sz_{ij} \right]^2 + \left[ y_y - b - tz_{ij} \right]^2 + \left[ (x_y - a) t + (y_y - b) p \right]^2}{\sqrt{s^2 + q^2 + 1}} - R = \min \tag{6}
\]

The elastic zone of the pin is obtained in the light of equations (5), (6).

\[
E = \max \left\{ \xi_y \right\} - \min \left\{ \xi_y \right\}
\]

\[
= \max \left\{ \frac{\left[ x_y - a - sz_{ij} \right]^2 + \left[ y_y - b - tz_{ij} \right]^2 + \left[ (x_y - a) t + (y_y - b) p \right]^2}{\sqrt{s^2 + q^2 + 1}} \right\}
\]

\[
- \min \left\{ \frac{\left[ x_y - a - sz_{ij} \right]^2 + \left[ y_y - b - tz_{ij} \right]^2 + \left[ (x_y - a) t + (y_y - b) p \right]^2}{\sqrt{s^2 + q^2 + 1}} \right\}
\]

\[
E(a, b, s, t, R) \text{ denotes the function with regard to } a, b, s, t, R, \text{ the function } E \text{ is optimized to the}
\]
minimum according to the requirement of the minimum zone evaluation method, i.e., the minimum elastic zone of the locating pin is reached. Therefore, the elastic variation zone optimization of locating pin is transformed into unconstrained optimization problem.

\[
\min E(a, b, s, t)
\]  

(8)

Suppose the minimum point \([a_1, b_1, s_1, t_1]\) is the datum axis parameter with respect to the minimum condition, thus its minimum value \(E(a_1, b_1, s_1, t_1)\) is the minimum elastic variation zone value of the locating pin. The appropriate elastic variation zone of the locating teeth is selected according to tolerance of the locating hole of the workpiece and the required workpiece accuracy.

4. Data acquisition and numerical calculation

In order to ensure that the data collected satisfy the demand of locating pin elastic variation zone, then 10 equidistant sections are selected along the axis direction, and 1000 data points are sampled equally in each section based on the bottom of locating pin. MATLAB is served to optimize the analysis and process of the collected data. Since four unknowns in the objective function for calculating the elastic zone of the locating pin, it is impossible to obtain the minimum point of the objective function once. Therefore, the minimum points of the objective function corresponding to the other two unknowns are obtained by defining two variables of four unknowns. Then the minimum points of the objective function corresponding to the unknown variables are obtained in the same way. Let the data are substituted into the objective function, the minimum value of the objective function is reached when

\[a_1 = 0.00483 \text{mm}, \quad b_1 = 0.01982 \text{mm}, \quad s_1 = 0.01264 \text{mm}, \quad t_1 = 0.0432 \text{mm},\]

i.e., \(E(a_1, b_1, s_1, t_1) = 0.06382 \text{mm}\). Therefore, the elastic variation zone of the elastic locating pin is 0.06382 mm. In this study, the design dimensions of two locating holes on the bottom of engine block are \(400 \pm 0.03 \text{mm}, 0.06382 \geq 0.06 \text{mm},\) i.e., then the maximum of the center distance tolerance of the locating hole is assimilated by the minimum elastic zone of locating pin teeth. Therefore, the workpiece accuracy is significantly improved through the adaptive change of the elastic teeth of the locating pin, and the clamping interference caused by the tolerance of the center distance of the locating pin and hole is irrespective simultaneously.

5. conclusion

1. The novel locating scheme of one plane and two pins does not need to consider the tolerance of the locating hole and the angular tolerance of the traditional one plane and two pins, but only the tolerance of the center distance between the two locating holes is respective. Since the locating pin is made of high quality spring steel, the high accuracy locating is realized through closest contact between the locating pin and hole due to the resilience of the elastic teeth. In addition, the center distance tolerance of the same batch of locating holes can be allowed to change within the elastic variation zone of the locating pin by changing the elastic teeth of the locating pin, thus the interference of workpiece clamping caused by the variation of the center distance tolerance is eliminated to large extent.

2. The locating tolerance between the two locating holes on the workpiece can be assimilated through the micro-elastic variation zone of the elastic pin teeth, consequently the relative unification of locating datum in a large batch of workpieces or for each workpiece in multi-process locating process are realized.

Reference
[1] Yu Shiwei, Design and calculation of double pin positioning [J]. Machine tool, 1980(03):9-12.
[2] Wang Weimo, Location of one side and two pins in fixture design [J]. Journal of Guizhou University of Technology (Natural Science Edition), 1987(02):51-58.
[3] A.Saravanan, C. Balamurugan, K. Sivakumar, S. Ramabalan. Optimal geometric tolerance design
framework for rigid parts with assembly function requirements using evolutionary algorithms [J]. The International Journal of Advanced Manufacturing Technology, 2014(73) 1219-1236.

[4] Zhang Junjun, Wang Jisheng, Probabilistic design of positioning accuracy for one side and two holes [J]. Journal of Southwest University of Science and Technology, 1996, 03: 46-49.

[5] Lv Cheng, The Study on Prediction and Optimization of Assembly Accuracy based on Joint Surface Error Modeling [D]. Hunan University 2016: 2-11.

[6] Vembu V, Ganesan G. Heat treatment optimization for tensile properties of 8011Al/15% SiCp metal matrix composite using response surface methodology [J]. Defence Technology, 2015, 11(4): 390-395.

[7] Dong Zhimin, Bai Lanping. Fixture location in mechanical parts machining [J]. Journal of hefei university of technology, 2015, 38(8): 1033-1035. DOI: 10.3969/j.issn.1003-5060.2015.08.006.