Research on assembly accuracy of vertical launcher based on shape error

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Abstract. As an important part of the shipborne missile weapon system, the overall assembly accuracy of the shipborne vertical launcher will affect the initial accuracy of the test missile launch to varying degrees. Therefore, it is of great significance to research on the assembly accuracy of the launching device. Aiming at the geometric error characteristics of the contact surfaces between the assemblies in the launching device, this paper uses small displacement spins to represent the geometric error of the contact surfaces, and proposes a method for calculating the fit error based on the contact state. The research results show that this method can determine the contact state of the launcher assembly, and the influence of the shape error distribution of the contact surface on the precision assembly cannot be ignored.

1. Introduction
The assembly accuracy of the launcher is an important tactical and technical indicator in the vertical launch system, which affects the initial accuracy of the test missile launching to varying degrees, and directly determines the accuracy and killing efficiency of the missile attack target [1]. Shape error is an important component of surface topography error, and it is one of the key factors that affect the assembly accuracy of mechanical products. Different distribution characteristics of geometric shape errors usually result in different assembly contact states. The transmission and accumulation of geometric shape errors during the assembly process of the launching device will result in different assembly errors. Also, non-uniform contact conditions caused by geometrical errors can cause non-uniform stress on the part.

With the change of time, temperature and environment, the energy of the non-uniform stress field is gradually released due to the rheological changes of materials and structures, which ultimately leads to further changes in assembly errors and instability in assembly accuracy. And small errors will affect the changes in the structure of mechanical products, and thus affect the accuracy of the entire system. Considering the shape error, researching the contact state of precision assembly is of great significance to realize the prediction of assembly accuracy, optimize the assembly process, and improve the accuracy and stability of assembly [2].

In the study of contact analysis of precision assembly for shape error, domestic and foreign scholars have made a lot of researches. LYU C used the theory of small-displacement spin to mathematically describe the tolerance, and analyzed the problems of error mode and tolerance optimization of the assembly interface between parts under multiple tolerance coupling situations [3]. Li X B performed a feature analysis on the micro-morphology of different machined surfaces [4]. Fan H L proposed a method for determining the parameters of shape errors for precision assembly [5]. Zuo
F C proposed a method for contact analysis of mating surfaces under the combined effect of shape error and assembly force [6].

2. Geometrical error distribution characteristics of part surface

For the planar characteristics of parts, the flatness is used to represent the size of the shape error, and the flatness $\Delta$ is a scalar value, which cannot represent the fluctuation of the actual machining plane height. The flatness of the two-part surfaces is the same, but the geometric distribution of the shape error is different. When the two parts are assembled, the spatial geometric position of the actual contact surface changes differently, thereby affecting the assembly accuracy of the product. Therefore, the shape error has a significant impact on the assembly accuracy of precision parts. The topological structure of the assembly determines the assembly relationship between the various components. The parts are assembled through the geometrical surfaces of each other according to the assembly relationship.

![Image](https://i.imgur.com/123456.png)

Figure 1. Geometrical errors of parts with the same flatness

It can be seen from figure 1 that the shape error distribution of the part surface is different.

For high-rigidity precision parts, due to the shape error, the mating surfaces are contacted through a limited number of points when the two parts are assembled, rather than the entire mating surface is in full contact. After the position of the contact is determined, the spatial posture of the parts to be assembled can be determined, thereby determining the assembly accuracy of the assembly. The measurement data of the contact surface between the vertical launchers are now adopted by the measuring instrument. Based on the respective measurement coordinate systems, the measurement data of the mating surfaces of the assembled reference part and the assembled part are shown below.

$$A^R_i = [A^R_{i1} A^R_{i2} \ldots A^R_{im}], \quad A^P_i = [z^P_{i1}, z^P_{i2}, \ldots z^P_{in}]$$

(1)

$$A^R_j = [A^R_{j1} A^R_{j2} \ldots A^R_{jm}], \quad A^P_j = [z^P_{j1}, z^P_{j2}, \ldots z^P_{jn}]$$

(2)

In the formula (1) and (2), $A^R_i$, $A^P_i$ are the measured data of the mating surface of the assembly reference part and the assembled part. Assuming that there are $m$ rows and $n$ columns of measurement points on the part surface, and $z^R_{i,j}$, $z^P_{i,j}$ are the $z$-coordinate values of the $i$-th row and the $j$-th column measurement points on the reference part and the assembled part. The position and number of points sampled by the two contact surfaces should be consistent.

Before registration, the two mating surface data measured in their respective measurement coordinate systems are converted to the same coordinate system. At the same time, to avoid interference between the two mating surfaces, the highest point on the reference part and the lowest point on the assembly are placed on a plane formed by the $x$ and $y$ axes of the common coordinate system. In the common coordinate system, the measurement data on the mating surfaces of the reference part and the assembled part can be expressed as follows.

$$z^R_{i,j} = \max \{z^R_{i,j} \mid i = 1,2,\ldots,m; \ j = 1,2,\ldots,n\}, \quad A^R_{i,j} = A^R_{i,j} - z^R_{i,j} \cdot I_{m \times n}$$

(3)

$$z^P_{i,j} = \max \{z^P_{i,j} \mid i = 1,2,\ldots,m; \ j = 1,2,\ldots,n\}, \quad A^P_{i,j} = A^P_{i,j} - z^P_{i,j} \cdot I_{m \times n}$$

(4)
In the formula (3) and (4), $I_{mn}$ is a matrix with $m$ rows and $n$ columns, and each element is 1. The distance surface can be expressed as $A^d = A^p_3 - A^p_2$.

This paper will collect data according to the style of figure 2.

3. Contact point fit error calculation

When two parts are assembled, the shape error between the two mating surfaces will cause minor changes in the assembled part relative to the reference part, which will cause the actual assembly position and direction of the assembled part to change from the ideal assembly position and direction. This kind of position error and direction error is coordination error. First, we need to study the error of the surface characteristics of the fitting parts. Here, we refer to the small displacement spin as a vector consisting of a small displacement of a rigid body with six motion components. It is suitable for expressing the deviation of ideal shape features. The small-displacement rotation can be expressed as $D = (\alpha, \beta, \gamma, u, v, w)$. $\alpha, \beta, \gamma$ represent small fluctuations in rotation around the x, y and z axes, and u, v, w represent small fluctuations in translation along the x, y, and z axes. In the research scope of this article, the SDT method will be used to describe the variation of characteristic errors. For plane fit, only the error of the part along the z-axis direction is considered. Therefore, the small displacement spin of the plane characteristic error is expressed as $D = (\alpha, \beta, 0, 0, 0, w)$.

For plane fit, the mating surface contact points on reference piece $P_1$ are $(x_1, y_1, z_1^p_1)$, $(x_2, y_2, z_2^p_1)$, $(x_3, y_3, z_3^p_1)$, and the mating surface contact points on reference piece $P_2$ are $(x_1, y_1, z_1^p_2)$, $(x_2, y_2, z_2^p_2)$, $(x_3, y_3, z_3^p_2)$. The plane equation can be calculated from the 3 points obtained.

\[
P_1: z = A_1x + B_1y + C_1
\]
\[
P_2: z = A_2x + B_2y + C_2
\]

In the formula (5), $A_1$, $B_1$, $C_1$ and $A_2$, $B_2$, $C_2$ are the coefficients of two plane equations. Then the angles between the normal vector of the $P_1$ plane and the x and y axes are

\[
\cos \alpha_1 = (n_1 e_x) / (||n_1|| e_x),
\]
\[
\cos \beta_1 = (n_1 e_y) / (||n_1|| e_y),
\]

In the formula (6), $n_1$ is the surface normal vector of $P_1$ and $e_x$, $e_y$ are unit vectors of the x-axis and y-axis. Similarly, the angles between the normal vector of $P_2$ and the x and y axes are

\[
\cos \alpha_2 = (n_2 e_x) / (||n_2|| e_x),
\]
\[
\cos \beta_2 = (n_2 e_y) / (||n_2|| e_y),
\]
In the formula (7), $n_2$ is the surface normal vector of $P_2$ and $e_x$, $e_y$ are unit vectors of the x-axis and y-axis. $(x_{p_1}, y_{p_1}), (x_{p_2}, y_{p_2})$ are the center points of the mating planes of $P_1$ and $P_2$. In the formula (8), $w_1, w_2$ are translations in the z-axis direction of the characteristic error.

$$
 w_1 = A_1 x_{p_1} + B_1 y_{p_1} + C_1
$$

$$
 w_2 = A_2 x_{p_2} + B_2 y_{p_2} + C_2
$$

In the formula (9), the fitting error between the two assembly parts is expressed as follows.

$$
 u = (\alpha_1 - \alpha_2, \beta_1 - \beta_2, 0, 0, 0, w_1 - w_2)
$$

Based on the sampling data of each contact surface of the assembly, the final assembly error calculation results can be obtained using the above assembly error calculation method as shown in the table.

| Number | Assembly error |
|--------|----------------|
| Assembly 1 | $u_1 = (-8.68e - 4, -7.19e - 4, 0, 0, 0, 6e - 3)$ |
| Assembly 2 | $u_2 = (-1.15e - 3, 3.19e - 3, 0, 0, 0, 7e - 4)$ |
| Assembly 3 | $u_3 = (5.78e - 4, 2.87e - 4, 0, 0, 0, 5e - 3)$ |
| Assembly 4 | $u_4 = (-1.53e - 4, -2.88e - 4, 0, 0, 0, 6e - 3)$ |

Table 1 shows the errors between the various assemblies.

4. Conclusion

This paper analyses the geometric error characteristics of the contact surfaces between assemblies, and proposes a method for calculating the fit error based on the contact state of the assemblies. This has important guiding significance for the prediction of assembly accuracy, optimization of assembly technology, and improvement of assembly accuracy and stability.

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