Analysis Method of Degrees of Freedom for Integrated Positioning

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Abstract: In order to ensure the machining requirements, the very first issue to be solved during machining is the positioning of workpieces on lathes or fixtures. Due to different shapes of workpieces, integrated positioning is adopted in most cases. While, the analysis of degrees of freedom for integrated positioning is quite difficult, therefore, the author developed a certain analysis method of degrees of freedom for integrated positioning—individual part analysis. It has been used to solve many workpiece positioning problems, which can provide much reference for design and analysis of positioning scheme.

Key Words: Integrated positioning; Positioning Element; Degrees of freedom

Positioning is required for workpiece before machining in order to ensure the required dimension and accuracy of workpieces. The workpiece positioning is fundamentally to limit the degrees of freedom that may have negative effect. As workpieces have different shapes in actual manufacturing, integrated positioning of two or more surfaces is taken instead of single surface. There is much difficulty to analyze the degrees of freedom for integrated positioning. In most textbooks, determination of limited degrees of freedom of integrated positioning is described vaguely, mainly focusing on conceptual expression and experience, and there isn’t an effective and universal analysis methodology. Thus, the author developed a certain method of the analysis of degrees of freedom for integrated positioning, which is individual part analysis. It was used to solve sorts of workpiece positioning issues, which is of much reference for design and analysis of positioning scheme.

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1 Analysis of Common Positioning Element

1.1 Realizing and Analysis of Positioning

Positioning is realized on the contacts of positioning elements and workpiece surfaces, that is, the positioning element and workpiece surface shall have a close contact. The separation of two will lose the limitation of degrees of freedom. The paper believes that the relative movement of element and positioning surface of workpiece is a right way to analyze limited degrees of freedom of common positioning element.

On the base of that the close contact between workpiece and the positioning element, the workpiece has six independent movements in the space. Assuming that the workpiece moves or rotates along or around the three axes of coordinates (both forward and reversal), the element does not limit the degrees of freedom if the workpiece keeps close contact with the positioning element when moving or rotating. Conversely, if the workpiece leaves the positioning element, the degrees of freedom of positioning element is limited along this direction. The determination of degrees of freedom limitation is based on contact during individual movement, which is summarized as "separation resulting in limitation and contact leading to no limitation.

1.2 Ideal Assumption

The integrated positioning method is formed by a group of reasonable common positioning elements. There are many terms like short/long pin and long/ short three-jaw chuck fixation in textbooks. But how do we understand “long” and “short”? The author advises an ideal way. “Long” can be regarded as “infinite long”, which is equivalent of large surface contact, while “short” can be thought as “infinite short”, which is equivalent of line contact. That is to say, the contact area between positioning element and workpiece is considered to be geometric point, line or surface. “Long” or “short” positioning element in actual working shall be determined by the function of positioning element. This means the dimension of positioning element and size of workpiece positioning surface are relative instead of absolute.

Infinitive small surface can be treated as a point, like the small contact between supporting screw and workpiece which can be taken as point contact and 1 degree of freedom can be limited. However, the narrow surface can be treated as a line, such as the contact between strip supporting plate and workpiece, of which 2 degrees of freedom can be limited.

When the workpiece is positioned by a hole, the common positioning element is spindle. There are long spindles and short spindles. The short spindle has short contact with inside hole of workpiece, which can be taken as line contact and the degrees of freedom along two movement directions can be limited. The long spindle has long contact with workpiece, which can be considered as large surface contact or two line-contacts and 4 degrees of
freedom can be limited (two movement degrees of freedom and two rotating degrees of freedom).

For those workpieces positioned by outside cylindrical surface, such as sleeve, chuck and v-block, there are long ones and short ones with same positioning method as spindle.

2 Individual Part Analysis for Integrated Positioning

Individual part analysis is a way to analyze the limited degrees of freedom based on the constraints imposed on each positioning surface respectively in full consideration of interaction between each positioning element. The analysis is described as below:

1) First of all, analyze the degrees of freedom limited by single positioning element with method same as “1 Analysis of Common Positioning Element”.

2) For integrated positioning, the limitation on rotation degrees of freedom by individual positioning element remains unchanged. If there is no overlying between limited movement degrees of freedom, the limitation on movement degrees of freedom by individual positioning element remains unchanged. In case of overlying, the limitation shall be analyzed for further determination, with method below: (1) The primary and secondary positioning elements shall be differentiated if there are overlying degrees of freedom. Commonly, the positioning element with more degrees of freedom limitation is taken as primary positioning element and the less as secondary. If it is unable to make a difference, hypothesis can be adopted. (2) The limitation on movement degrees of freedom by primary and secondary positioning elements remain the same. (3) Move the secondary positioning element along overlying direction. The trend caused by workpiece is degrees of freedom limited by the secondary positioning element.

3 Application Examples

3.1 Integrated positioning of Two Positioning Elements

Two lathe centers clamping is a common way in machining industry. Shown as Fig. 1, the workpiece is positioned by two centers in front and rear end. The front is a fixed center and the rear one movable center adjusted on X axle.

![Figure 1. Workpiece Positioning with Two Centers.](image-url)
For single positioning, the front center limits the $\vec{x}$, $\vec{y}$ and $\vec{z}$ movement degrees of freedom. The float rear center limits the $\vec{y}$ and $\vec{z}$ movement degrees of freedom. When the front and rear center combine to position, there is no overlying between the $\vec{x}$ degrees of freedom limited by the front center and rear center degrees of freedom, therefore, $\vec{x}$ degrees of freedom remains and $\vec{y}$ & $\vec{z}$ have overlying, so the degrees of freedom limited by the two centers shall be analyzed and determined again. The front center limits more degrees of freedom, which can be taken as primary positioning element and the rear center taken as secondary element. $\vec{y}$ & $\vec{z}$ movement degrees of freedom limited by the front center remains the function during integrated positioning and move the rear center towards the front center along the overlying $\vec{y}$ direction. The workpiece has rotary trend around Z axle, which limits $\vec{z}$ degrees of freedom. Then move the rear center towards the front center along the overlying $\vec{z}$ direction. The workpiece has rotary trend around Y axle, which limits $\vec{y}$ degrees of freedom. In conclusion, the two centers integrated positioning limits total five degrees of freedom: $\vec{x}$, $\vec{y}$, $\vec{z}$, $\vec{y}$ and $\vec{z}$.

3.2 Integrated positioning with Several Positioning Elements

Fig. 2 is positioning program when the headstock is set for boring. Four positioning elements are there – 1 & 2 are short circular cylinder, 3 strip supporting plate and 4 supporting screw. Based on the analysis of degrees of freedom limited by positioning elements, when single positioning element takes effect,

Short circular cylinder 1: limits $\vec{x}$, $\vec{z}$; Short circular cylinder 2: limits $\vec{x}$, $\vec{z}$; Strip supporting plate 3: limits $\vec{z}$, $\vec{x}$; Supporting screw 4: limits $\vec{y}$.

(a) 3D Drawing                       (b) Headstock Positioning

Figure 2. Positioning for Headstock Boring.

Based on individual part analysis, the role that strip supporting plate 3 limit $\vec{x}$ degrees of freedom remains the same for integrated positioning and the limitation on $\vec{y}$ degrees of freedom of supporting screw 4 has no overlying with same function. The short cylinder 1 & 2 and strip supporting plate 3 limit
degrees of freedom and short cylinder 1 & 2 limit \( x \) degrees of freedom with overlying. The three positioning elements has same limited degrees of freedom, therefore, it is difficult to tell the primary and secondary. Suppose short cylinder 1 is primary positioning element, cylinder 2 as secondary and strip supporting plate as third positioning element. The \( x \) and \( z \) movement degrees of freedom limited by primary positioning element remain the same in integrated positioning. Move the secondary positioning element – short cylinder 2 along direction \( x \) relative to primary element – short cylinder 1, and the workpiece has rotation trend around \( Z \) axis, which limits \( z \) degrees of freedom. Then move the third positioning element – strip supporting plate 3 along direction \( z \) relative to primary element – short cylinder 1, and the workpiece has rotation trend around \( Y \) axis, which limits \( y \) degrees of freedom. To be concluded, of the integrated positioning, the actual degrees of freedom limited of each positioning element are shown as below:

- Short circular cylinder 1: limits \( x, z \)
- Short circular cylinder 2: limits \( x, z \)
- Strip supporting plate 3: limits \( z, x \)
- Supporting screw 4: limits \( y \)

To be concluded, 6 degrees of freedom of the workpiece are all limited with overlying of \( x \) degrees of freedom by short circular cylinder 2 and strip supporting plates 3, which is over-positioning. When machining of workpiece base surface or positioning element of fixture has error, the workpiece will be deformed after clamping, resulting in machining accuracy. However, upgrade the machining accuracy of workpiece positioning base surface and fixture positioning element will ensure the shape of fitting fixture. Therefore, as during positioning, contact area is larger, resulting in improved rigidity and little vibration happens due to stable profiling, which ensure machining accuracy. So it is the positioning method commonly adopted.

4 Conclusion

Limited degrees of freedom by common positioning elements is the determination basis of degrees of freedom with integrated positioning. Individual part analysis firstly focuses on degrees of freedom limited by single positioning element. The degrees of freedom limited by positioning element for integrated positioning is analyzed afterwards. In actual production, combination of several positioning surface instead of single surface is mostly encountered. With certain methods, the analysis of degrees of freedom for integrated positioning can be easier. The individual part analysis described in this paper and can help us determine degrees of freedom limited actually by each positioning element effectively and quickly with less effort.

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