Development and Design of Detachable Deep Hole Variable Diameter Boring Tool Device

Zhanfeng Liua, Kun Wangb*, Yazhou Fengc, Zhanhui Lid

Department of Mechanical Engineering, Xi’an Petroleum University, Xi’an, Shaanxi, China

*Corresponding author’s e-mail: 413879566@qq.com

c-e-mail: 181205@xsyu.edu.cn
d-e-mail: 1808612891@qq.com

Abstract—In order to solve the problem of deep hole processing, the inner reaming of small ends and large middle is difficult to process. Developed and designed a detachable deep hole variable diameter boring tool device with self-centering, replaceable tools, and capable of changing the same diameter of the guide block and the tool and with self-locking function. Introduce in detail the structural features, assembly conditions and design principles of the detachable deep hole variable diameter boring cutter device. It provides an effective solution for the processing of inner reaming in deep holes.

1. Introduction

With the continuous innovation of modern processing and manufacturing technology and the requirements of product diversification, there are also some problems in the field of deep hole processing. When processing the inner reaming of a certain section of deep hole parts, that is, the so-called reaming with small ends and large middle [1-2], as shown in Figure. 1, the definition of deep hole is that the ratio of hole depth l to diameter D is greater than 5 [3], and the inner expansion of a certain section is processed in this kind of deep hole. The conventional reamer and boring cutter are difficult to process and manufacture.

This kind of inner reaming is mostly used for weight reduction and vibration reduction of large cylinder block and aircraft landing gear. It is also more and more needed in some special purpose parts of civil and military industries, such as small ends at both ends and large length diameter ratio in the middle.

In order to solve this problem, a detachable deep hole variable diameter boring tool device is developed and designed. The detachable deep hole variable diameter boring tool device combines reaming with rough and fine boring. The same diameter expansion of the tool and the guide block can be realized through the rotation of the screw disk, so as to ensure the coaxiality of the inner reaming and through-hole, reduce the vibration of the cutter in the processing, ensure the processing quality of the hole, and be stable and accurate in the control, and the processing method is simple, fast, economical and practical, which greatly expands the deep hole machining and manufacturing function of boring machine.
According to the special structure of the parts, the deep hole variable diameter boring cutter must meet the following requirements:

- After the boring tool body enters the appropriate position from the through hole, the boring block can be forced to extend gradually and cut in gradually. After the boring tool block is fixed in place, the cutting can be continued to ensure that the inner hole with the required diameter can be bored. When the tool feed reaches the corresponding position, the boring block can be retracted into the tool body by adjusting the boring tool block, so that the boring tool can exit from the through-hole, and the machined surface will not be damaged. The radial dimension of the tool body after retraction must be less than the diameter of the through-hole.
- It is required that the boring tool body can guide and support itself in the hole, so as to enhance the rigidity of the boring tool in the process of machining.
- The boring cutter body should have a certain space for chip holding and chip removal, and the chip can be forced to discharge along a certain direction through a certain pressure cutting fluid.

2. Development and design of detachable deep hole variable diameter boring tool device

2.1. Structural features

The schematic diagram of detachable deep hole variable diameter boring cutter device [4] is shown in Figure. 2, and the three-dimensional assembly of detachable deep hole variable diameter boring cutter head is shown in Figure. 3. It has the following remarkable characteristics:

2.1.1. The concentricity change between the tool and the guide block at the boring head.
The spiral disk designed according to Archimedes spiral [5] can realize the concentric change of the cutter and the guide block at the same speed, so as to ensure the cutting stiffness, reduce the vibration during the cutting process, and ensure the coaxiality and surface processing quality.

2.1.2. Machine clamped carbide blade is adopted.
It has the advantages of convenient clamping, long service life, saving cutter body material, timely replacing the blade when the tool is worn or damaged, and improving the processing efficiency.

2.1.3. The I-shaped guide rail is used to realize the radial guide of the tool.
To ensure the rigidity requirement of the cutting tool, the vibration in the machining process is greatly reduced and the machining quality is improved.

2.1.4. The front row chip can be used for pulling boring cutting and pushing boring cutting.
The cutting process vibration is small, the surface processing quality is high, and the chip can be directly flushed out from the front end of the through-hole by high-pressure cutting fluid.

2.1.5. One side expansion is large.
The unilateral expansion and contraction of the device can reach (2 ~ 20) mm.
2.1.6. *It has the advantages of simple operation, multiple functions and wide application range.*

The radial change of the tool can be realized by adjusting the servo motor, and different holes can be processed by changing the clamping tool.

2.1.7. *The diameter is changed through the screw guide.*

On the basis of helix, it can ensure the precision requirement of variable diameter machining. At the same time, it has the function of self-locking to reduce the vibration in machining.

![Figure 2 Schematic diagram of detachable deep hole variable diameter boring cutter device](image)

![Figure 3 Three dimensional drawing of detachable deep hole variable diameter boring cutter head](image)

3. **Design principle of detachable deep hole variable diameter boring tool device**

3.1. *Design of screw disk and claw*

The claw and the spiral disc are combined to form a 120 degree radial distribution, and the radial change of the claw can be realized by rotating the spiral disk, as shown in Figure. 4. The spiral guide rail on the screw disk is designed according to Archimedes spiral line (also known as constant speed spiral line). It is matched with the tooth arc curve of the claw [6]. The claw is equipped with a cutter block and a guide block, which can be disassembled and replaced according to the processing requirements.

![Figure 4 Assembly drawing of claw and screw disk](image)

The radial force acting on the arc surface of the claw is the main basis for determining the jaw pitch. The pitch of the spiral pair curve is determined by combining the radial difference between the
through-hole to be processed and the inner expanding hole. At the same time, it is necessary to ensure that at least two teeth on the claw are engaged with the teeth on the spiral disc, so as to determine the jaw pitch, and make the pitch of Archimedes spiral used in the spiral disk plane design with it equal.

According to the characteristics of the screw disk, when the axial position of the claw is fixed, the rotation of the screw disk can drive the radial expansion and contraction of the claw. The radial expansion length of the claw can be controlled by external adjustment to complete the processing of the inner expanding hole in the deep hole.

3.2 Static analysis

The internal reaming is carried out by axial feeding and broaching with the workpiece rotating cutter. The stress condition of the three claws [7] is shown in Figure. 5.

In the process of machining, the cutting force $F_c$, radial force $F_p$ and axial force $F_f$ are generated by the tool on the tool claw; the guide block on the guide block jaw is squeezed by $N_1$ and $N_2$ between the hole wall, the friction force $F_{f1}$ and $F_{f2}$ generated when the guide block rotates relative to the hole wall, and the axial friction force $F_{fx1}$ and $F_{fx2}$ generated between the hole walls when the guide block moves along the axial direction.

The cutting force $F_c$, friction force $F_{f1}$ and $F_{f2}$ are balanced supported by the assembly of claw guide rail cover and end cover; radial force $F_p$, extrusion force $N_1$ and $N_2$ are balanced supported by the assembly of claw teeth and screw disk upper teeth; axial force $F_f$, axial friction force $F_{fx1}$ and $F_{fx2}$ are balanced supported by assembly with end cover and claw guide rail cover.

When the tool claw is subjected to the radial force $F_p$ in the radial direction, the claw and the spiral disc will produce self-locking phenomenon, which ensures that the radial position of the cutter block and the guide block remains unchanged, and improves the accuracy of the internal reaming processing. The force of the claw tooth and the screw disc tooth at the meshing point is shown in Figure. 6. Since the engagement point of the claw tooth and the screw disc tooth are in the same concentric circle, the pressure on the jaw and the screw is the same. The reaction $F_p'$ produced by the rotating disc teeth is balanced in the radial direction and reaches the self-locking condition (the other two guide block claws are the same).
3.3. Control of tool diameter change
The accurate control of tool diameter change ensures the quality of the cutting hole, and reasonable and effective control of the radial change of the tool plays an important role in improving the machining accuracy of the hole. The radial expansion and contraction of the tool is driven by the rotating mandrel to rotate the screw disk, thus driving the claw to realize the radial expansion and contraction change, as shown in Figure 7.

![Figure 7 Assembly diagram of jaw](image)

The three claws are respectively equipped with a cutter block and two guide blocks, and the outer diameter of the tool and the guide block are in the same concentric circle. Therefore, when the rotating mandrel drives the spiral disk to rotate, the tool radial change is realized, and the guide block changes together to make the three points in the same circle. According to the screw pitch selected by the screw disk, the extended length of the claw can be determined for each turn, so as to ensure the precise expansion and extension of the tool and the requirements of rigidity and stability in the process of reaming in deep holes.

4. Process flow of inner reaming
Because the reaming process of deep hole is carried out under the condition of through hole, it is impossible to use boring cutter to carry out internal reaming directly. Firstly, the two guide block claws are removed for assembly, and a pre hole is pre processed at the position to be processed, and the axial length is greater than the length of the guide block installed on the claw. At this time, the tool and the guide block on the boring bar are not in the same concentric circle, and the circle radius corresponding to the tool is larger than that of the guide block on the boring bar, as shown in Figure 8. Then withdraw the cutter and install the guide block claw assembly. Rotate the spindle at the pre hole to make the three claws extend out at the same time and have the same diameter with the pre hole. Then, the axial feed is used for broaching. The chip is punched out from the front end of the through-hole by high-pressure cutting fluid to realize the complete deep hole reaming.

![Figure 8 The corresponding cutting circle when the claw is assembled without guide block](image)
5. Conclusion
This detachable deep hole variable diameter boring tool device not only has the processing performance of traditional boring cutter, but also has the diameter changing function that the traditional boring tool can not achieve. Its structure is simple and practical, easy to process, easy to purchase parts and strong universality. On the deep hole boring machine, this device can be used to realize the inner reaming, rough boring and semi precision boring of deep holes, and meet the requirements of surface processing accuracy and quality. The most obvious advantage of this device is that: the tool and guide block have self-locking function, and the tool and guide block can ensure real-time three-point common circle, to ensure the rigid requirements of the tool in the process of processing. By adjusting the screw disk, the machining accuracy and surface quality can be ensured. The structure is simple and easy to operate. The radial change and expansion of the tool and guide block can be realized only by adjusting the servo motor The function of the original deep hole boring machine is improved, the production efficiency is greatly improved, and the processing difficulty that the original machine tool can not enlarge the hole inside is solved.

Acknowledgment
Xi'an Shiyou University Postgraduate Innovation and Practice Ability Cultivation Funding Project (No. YCS19121009)

References
[1] Zhang, W.W.; Qian, L. On the processing of deep hole with small diameter at both ends and large in the middle[J]. Private science and technology, 2013 (04): 5.
[2] BIERMANN D, BLEICHER F, HEISEL U, et al. Deep Hole Drilling [J]. CIRP Annals, 2018, 67(2): 673-694.
[3] Liu, Z; Han, X, L. (2020) Deep hole processing technology for typical difficult to machine materials. Science Press, Beijing.
[4] Zhao, R. Research and development of inner reaming technology based on deep hole boring machine [D]. Shanxi: Zhongbei University, 2012.
[5] Luo, H.C, Zhou, B.L. Application and discussion of Archimedes spiral in mechanical engineering  [J]. Journal of Chongqing University of technology and Technology (NATURAL SCIENCE EDITION), 2015,32 (06): 90-93.
[6] Zeng, X.S. Curve design of three jaw chuck plane screw pair [J]. Sichuan machinery. 1981 (1): 10.
[7] Chen, R.Y. (2012) Principle of metal cutting. China Machine Press, Beijing.