Design and Simulation Analysis of Cutter in New Sewer Dredging Device

Xueqing Hu \(^1\ast\), Peijun Liang \(^2\), Yifan Shen, Aoxiang Tian, Menglan Yang

\(^1\)Mechanical Design, Manufacturing and Automation, Wuhan University of Technology, Wuhan, Hubei Province, 430063, China
\(^2\)Mechanical Design, Manufacturing and Automation, Wuhan University of Technology, Wuhan, Hubei Province, 430063, China
\(^\ast\)Corresponding author’s e-mail: 1450893458@qq.com

Abstract. The existing sewer dredging method can not meet the needs of high-speed operation of the city. Through the research and analysis of the cutterhead of the shield tunneling machine, combined with the requirements of the sewer environment and dredging work, three-dimensional model, Ansys simulation analysis and physical experiments are adopted. In this way, a new type of spoke panel cutter head was designed. The cutter head adopts a new type of scraper. The structure is exquisite and the assembly is simple. It can effectively clear the sediment in the sewer environment and complete the initial recovery of the silt.

1. Preface

As an important part of the urban drainage system, the sewer is responsible for the collection and transportation of urban sewage and waste water[1]. The composition of the pollutants discharged from the pipeline is complicated. Once it is blocked, it will cause inconvenience to people's work and life, and even cause huge economic losses and security threats. Therefore, the clean-up of sewers is of great significance to the people's life and the development of the city.

On the one hand, China's cities have developed rapidly in recent years, and the initial design of urban drainage systems is difficult to meet the requirements of later development[2], causing the sewer to be easily blocked. On the other hand, the relevant regulations and regulations on the maintenance and management of sewer pipes are lacking[3], and a large amount of foreign materials are discharged into the sewers, which increases the difficulty of dredging and makes the sewer pipes difficult to clean.

There are two main ways to improve this situation: re-planning urban drainage systems and improving the efficiency of sewer dredging. Today, with the rapid development of the city, large-scale reconstruction of sewers is obviously not in line with the reality, so finding a more efficient and convenient dredging method is the best way to solve the current situation of sewers.

At present, the mainstream sewer dredging methods include the slow-car dredging method, the water flushing method and the high-pressure water jet dredging method[4]. These three traditional methods of dredging have their own strengths, respectively in different environments. Widely used in applications, but all have shortcomings such as low efficiency, high energy consumption, and difficult operation, and it is impossible to achieve high-efficiency dredging.

In order to solve the above problems, a new type of multi-functional dredging device is designed. The whole machine consists of four parts: cutting device, walking device, sludge collecting device and motor control device. In the cutting device, the cutter head is the most direct cleaning device. The size
of the tool will directly affect the structural dimensions of other parts as well as the efficiency and quality of dredging. In order to meet the requirements of performance, economy and environmental protection, a new cutter disc structure suitable for dredging of sewers was designed.

2. Overall design of the cutter head

The domestic sewer pipe wall is mostly made of reinforced concrete. The inner diameter of the pipe is 0.8-1.2 m. The silt is mainly composed of silt, plastic, stone and construction waste. It has certain cleaning difficulty. Considering the similarity between the sewer environment and the mining environment such as the shield tunneling machine, based on the basic structure of the cutterhead of the shield tunneling machine and the relevant characteristics of the sewer environment, a cutterhead that meets the dredging requirements of the sewer is designed.

The front and side structure diagrams of the new cutter head are shown in Figure 1 and Figure 2. The dimensions are shown in Table 1. The spoke-type cutterhead is used as the front cutterhead, and the special cutter is mounted on the front cutterhead, each spoke and panel. A scraper is mounted on the right side, and the scraper is connected to the front and rear cutter heads. The rear cutter disc is made of a circular baffle having the same diameter as the front cutter disc, and six discharge ports are opened in the center of the baffle plate.

The new cutter head needs to be dredged in the sewer environment and should have good rigidity and corrosion resistance. The cutter blank is cast, so the material needs to meet the casting process requirements. The cast aluminum alloy zl105 has excellent corrosion resistance and good mechanical properties[5]. Therefore, the cast aluminum alloy zl105 is selected as the material of the cutter main body.

| Table 1. New cutter head size parameters |
|-----------------------------------------|
| Outer diameter of the inside diameter  |
| thickness                               |
| Panel center angle                     |
| Spoke center angle                     |
| New cutter head                        |
| 750mm                                   |
| 670mm                                   |
| 35mm                                    |
| 50°                                     |
| 34°                                     |

Among them, the opening ratio of the spoke-type cutter head and the angle of the scraper have a great influence on the dredging efficiency, quality and service life of the cutter disc, so it is designed and studied.

2.1 Working principle

While the motor drives the cutter head to rotate, the whole machine begins to move forward. The scraper on the surface of the cutter disc penetrates into the sluice of the knot. During the rotation process, the
surface layer of the first contact cutter disc is separated by the cutting action and the pushing action of the rake face. The newly separated silt debris is temporarily The scraper is loaded (Figure 3).

During the cutting process, the body moves forward at a constant speed, and the thrust of the baffle causes the debris of the stopper to enter several collection grooves composed of spokes, panels, scrapers and baffles. Under the action of the centrifugal force component generated by the single-direction rotation of the cutterhead and the thrust of the scraper, the crushed silt is gradually concentrated near the discharge port, and finally falls from the discharge port into the sludge collection device after the influence of its own gravity. (Figure 4).

The new cutterhead has made a large adaptability modification while drawing on the cutterhead structure of the shield tunneling machine. It has a new working principle and workflow, and can effectively dredge the sewer environment.

![Fig. 3 Schematic diagram of scraper cutting](image1)

![Fig. 4 Schematic diagram of scraping material recovery](image2)

2.2 scraper design

The sewer fouling is mainly sludge, so a scraper that can quickly cut and temporarily carry the object to be cut is selected as the cutter[6]. The scraping action of the blade passes through the cutting action of the cutting edge and the pushing action of the rake face to cause stress and deformation of the blocked plug of the cut. The cutting action of the cutting edge causes the stress of the cutting layer to exceed the strength of the internal bonding of the fouling material, so that the cutting layer of the cutting layer is separated in the direction of the cutting edge. The pushing action of the rake face deforms the separated silt and separates it from the matrix to form debris.

Considering that the cutter head is work mainly under soft soil conditions, the concentric arrangement method and the Archimedes spiral arrangement method can meet the work requirements, but the latter is much more difficult to calculate and install than the former[7]. In order to reduce the difficulty in the design and manufacture of the cutterhead, and at the same time improve the accuracy of the installation[8], the force is evenly distributed, the cutting work can be completed better, and the cutters are arranged by the concentric arrangement method (Fig. 5).
2.3 spoke panel cutter head design
Spoke-type cutterheads have an opening ratio ranging from 25% to 45%. The sewer environment is special. Unsuitable opening ratios can cause machine damage or decontamination quality. Therefore, it is necessary to study the opening ratio of the new cutterhead.

If the aperture ratio is too small, on the one hand, some bulky silt (such as stones, plastics, etc.) will block the cutterhead. On the other hand, the wet sludge in the sewer may form a mud cake at the center of the cutterhead, and the cutter is blocked. The venting of the vents increases the torque of the central shaft and causes damage to the cutter head. At the same time, the torque received by the cutterhead during the working process is closely related to the opening ratio of the cutterhead. The torque of the cutter of the shield tunneling machine is reduced linearly as the aperture ratio increases[9]. It can be inferred that when the aperture ratio is too small. The cutter head may continue to operate at higher torques, making the spindle unable to meet the coaxiality requirements and ultimately affecting the life of the cutterhead.

If the aperture ratio is too large, the sewer fouling material as a semi-fluid body cannot form an effective extrusion. After the cutter surface has penetrated into the fouling part, the machine may also be unstable due to insufficient contact area between the cutter head and the fouling material.

After considering the above factors, it was decided to determine the cutter opening ratio as 30%.

3. Simulation analysis
During the operation of the cutter head, the spindle of the cutter head is subjected to a large torque. When the external load exceeds the tolerance of the part, the spindle may be deformed or broken. Therefore, an axis simulation analysis is performed on the cutter spindle to ensure its safety.

At the same time, the scraper on the surface of the cutter disc directly contacts the fouling material, which is subjected to large force and easy to wear. The force analysis is shown in Fig. 6. When the scraper material is determined, the angles of the rake angle $\gamma$ and the rear angle $\delta$ of the scraper are the cutting performance. And the decisive factor of wear and tear. Therefore, ANSYS simulation analysis is carried out on some specific angle scrapers to select the best overall scraper.

3.1 Material selection
From the material mechanical properties and economical considerations, the material of the cutter head spindle is 40Cr. The scraper works in the sewer environment, mainly cutting plastics and silt. It has low requirements on the mechanical properties such as hardness of the tool material, and the corrosion
resistance of the material is extremely high. Therefore, the cast aluminum alloy ZL108 is selected. The performance of the two materials is shown in Table 2:

| material | density (g/cm³) | Modulus of elasticity (Gpa) | Poisson's ratio |
|----------|----------------|-----------------------------|----------------|
| 40Cr     | 7.9            | 210                         | 0.3            |
| ZL108    | 2.7            | 72                          | 0.3            |

### 3.2 Shaft strength check

In order to ensure the normal operation of the cutterhead, ANSYS simulation analysis was carried out on its stress and strain. As shown in Fig. 7, the maximum stress of the main shaft is 4.2585 Mpa, the allowable stress of the main shaft material is 365 Mpa, and the maximum stress is much smaller than the allowable stress, which satisfies the strength requirement. As shown in Figure 8, the maximum strain of the spindle is 6.065 μm, which meets the coaxiality requirements of the spindle.

![Fig. 7 Stress analysis of the spindle of the cutter head](image1)

![Fig. 8 Strain analysis of the spindle of the cutter head](image2)

### 3.3 Force of the scraper and simulation analysis

The rake angle of the scraper suitable for the sewer environment is: 10° < γ < 20°, and the back angle range is: 5° < δ < 15°. Therefore, the γ angle and the δ angle are controlled to be constant, and stress analysis is performed on the doctor blade in a certain angle range.

The γ angle is controlled to be 20°, and the δ angles are 5°, 10° and 15° respectively. The ANSYS simulation analysis is carried out. As shown in Fig. 9, the maximum stresses of the three sets of scrapers are 0.1896 Mpa and 0.2062 Mpa. 0.2424 Mpa. The analysis can be obtained: within a certain range, when the γ angle is constant, the maximum stress value of the scraper increases as the δ angle increases.

![Figure 9 (ANSYS stress analysis of scrapers with δ angles of 5°, 10°, 15° and γ angles of 20°)](image3)

The δ angle is controlled to be 10°, and the γ angles are 10°, 15° and 20° respectively. The ANSYS simulation analysis is carried out. As shown in Fig. 10, the maximum stresses of the three sets of scrapers are 0.4633 Mpa and 0.2808 Mpa. 0.2157 Mpa. The analysis can be obtained: within a certain range, when the δ angle is constant, as the γ angle increases, the maximum stress value of the scraper decreases, as shown in Fig. 7.
Figure 10 (ANSYS stress analysis of razor blades with $\gamma$ angles of 10°, 15°, 20° and $\delta$ angle of 10°)

When selecting the scraper material, the corrosion resistance is mainly considered. The cast aluminum alloy zl108 is used with less hardness and poor wear resistance. Therefore, when selecting the blade angle, mainly from the aspect of service life, the blade with a rake angle of 20° and a back angle of 5° is finally selected.

4. Conclusion
The designed cutterhead can perform high-efficiency dredging for the sewer environment. The special scraper and specific opening ratio ensure the cutting efficiency, working quality and service life of the cutterhead. At the same time, the cooperation of the scraper, scraper and baffle makes the cutterhead. The diversification of the cleaning environment also makes the structure of the cutterhead more compact, easy to process and assemble, and provides a new way for the cleaning of urban sewers.

References
[1] Ai Hainan, Li Maolin, He Qiang, Long Tengrui. Research progress and prospects of sewage treatment in sewers [j]. China Water Supply and Drainage, 2013, 29 (12): 1-4.
[2] Hu Wei. Analysis and solution of problems in urban road water supply and drainage design and planning [j]. Engineering Construction and Design, 2019 (05): 172-173+176.
[3] Wang Shuzhi, Ma Xiufeng, Qu Xiuxian. Causes and prevention measures of urban drainage pipe blockage [j]. Forest Engineering, 2000 (02): 58-59.
[4] Li Jun. Dredging problem of urban drainage pipelines [j]. Heilongjiang Hydraulic Science and Technology, 2004 (01): 122-123.
[5] Huang Jianming, Chen Wei. Analysis of the selection and application of non-ferrous metal materials in mechanical design [j/ol]. World Nonferrous Metals, 2019 (14): 21+23 [2019-09-25].
[6] Huang Qingfei. Study on the interaction between shield cutter and soil and its selection design in sand and gravel stratum [d]. Beijing Jiaotong University, 2010: 22-26.
[7] Chen Guosheng. Application of Archimedes spiral in shield technology. Heavy Industry and Lifting Technology, 2006(2): 18-20.
[8] Zhou Qingxiang, Guo Jingbo, Yang Liang, Zhang Haidong, Zhang Chao. Design of cutter head for miniature earth pressure balance shield machine [j]. Mechanical Engineering and Automation, 2019 (01): 8-9.
[9] Jin Dalong, Yuan Dajun, Li Xinggao. Model test study on the influence of opening ratio of shield cutterhead on excavation parameters [j]. Modern Tunnel Technology, 2017, 54(02): 156-162.