Design and Research on Multifunctional Dredging Machine for Urban Sewer

Aoxiang Tian1, Yanfang Yang2*, Yifan Shen3, Peijun Liang4, Xueqing Hu5, Menglan Yang6, Zili Liu7 and Yongchao Li8

1Yujiatou Campus, Wuhan University of Technology, Wuhan, Hubei, China
2Yujiatou Campus, Wuhan University of Technology, Wuhan, Hubei, China
*Corresponding author’s e-mail: yangyanfang@whut.edu.cn

Abstract. The drainage pipeline is responsible for the collection and transportation of urban sewage and wastewater, and is one of the necessary facilities for the normal operation of the city. Therefore, it is of great significance to unblock and prevent the sewer pipe. A new type of dredging machine is designed to overcome the defects of the existing dredging method. The machine consists of two parts: a mechanical module and a control module. The machine adopts the idea of mechatronics which realize the automatic operation of the multi-function dredging machine, and it has low cost and good market economy benefits.

1. Introduction

The whole machine is mainly divided into two parts: mechanical module and control module.

The mechanical module consists of three different functional devices, namely the cutting device, the walking device and the sludge collection device. The cutting device completes the cleaning of the silt, the walking device ensures the stable movement of the body, and the collecting device realizes the collection and preliminary treatment of the sludge.

The control module is composed of an endoscope device, a speed sensor device and an electronic compass device. The speed sensor locates the position of the body in the pipeline by detecting the motor speed. The pipeline endoscope device collects the sewer wall health information, and transmits it to the computer. The electronic compass device monitors the movement direction and state of the device, and accepts the motion command. The Figure 1 is the chart of system flow.

![Figure 1. The chart of system flow](image-url)
1.1 Mechanical module

1.1.1 The device of cutter. The cutterhead is made of spoke-type cutterhead [1], which is suitable for the mud-water balance shield environment of the sewer. Considering that the machine works mainly under soft soil conditions, in order to make the tool arrangement convenient, it can be accurately placed at the required position, and the cutting task is better completed, and the tool is arranged by the concentric circle arrangement method [2]. A blade with a front and rear angle of 15° and 5° (Fig. 2) is mounted in the shape of a plurality of concentric circles on the surface of the cutter head to efficiently cut the mud formation. While the device is advancing, the scraper rotates with the cutter disc, and the cutting force of the axial direction along the fuselage direction, and the cutting force of the radial cutter tangential direction are generated for the excavation surface soil, and the cutting force is inserted through the cutting edge, and the cutter head portion. Cut the sludge into the silt and complete the sewer cleaning and dredging.

![Figure 2. Spoke Panel Cutter](image)

On the other hand, the blade passes the cutting action of the blade and the pushing action of the rake face, causing stress and deformation of the soil to be cut. The cutting action of the cutting edge causes the stress of the soil in the cutting layer to exceed the strength of the soil, so that the cutting layer soil is separated in the direction of the cutting edge. The pushing action of the rake face deforms the separated soil and separates it from the matrix to form soil debris. The swarf enters the opening with the front side of the squeegee, so the squeegee has both a cutting function and a loading function. With this feature, a certain number of scrapers are arranged on the spokes and panels of the spoke-type cutterhead. After the scraper cuts the sludge, the sludge enters the inside of the cutter disc. When the cutter disc rotates at a certain angle, the sludge moves to the center of the panel under the action of gravity, and is then collected from the opening around the center of the panel.

1.1.2 The device of sludge collection. Sludge contains a large number of pathogenic microorganisms and heavy metals such as copper, zinc and chromium, and also contains toxic and harmful substances that are difficult to degrade, such as polychlorinated biphenyls. However, sludge also contains a large amount of nutrients, which can be used as a useful resource after appropriate technical treatment [8]. A sludge collection box is installed in the front and rear parts of the body of the dredging machine. The collection box A of the fuselage head is connected to the main shaft and the cutter head, and receives the silage which is initially loaded after the cutter disc is cleaned. A pair of hobs are installed in the box to crush a relatively large volume of fouling. The collecting box A is connected to the collecting box B of the tail through a special pipe, and the crushed silage is sent to the collecting box B for collection under the flexible pushing action of the shaftless spiral blade. The Figure 3 is sludge collection device, the Figure 4 is crawler wheel device.
1.1.3 The device of walking. Three sets of wheel trains are used to support the dredging machine. Each set of wheels consists of an electric telescopic rod, several different gears, chains, motors and tracks. The fuselage forms a triangular prismatic walking mechanism, and each side of the triangular prism is installed. Two electric telescopic rods are connected to a crawler wheel, and the telescopic rod provides a certain pressing force to ensure stable movement and work of the dredging machine in the sewer.

Due to the influence of the topography, the inner diameter of the pipe wall of the sewer pipe will change continuously. In order to enable the dredging machine to work continuously and efficiently in the sewer, the device uses an electric telescopic rod to connect the casing and the crawler wheel, so that the wheel train can keep the body stable by adapting to the inner diameter of the sewer.

The track wheel can be used in all kinds of complicated road conditions, featuring light weight, high strength and reducing the amount of sagging and slipping of the body during operation [4], so the track wheel can be used for dredging in this device. The machine can move stably in the complicated environment of the sewer. At the same time, China's sewer pipes are mainly reinforced concrete materials, which are easy to be broken and difficult to repair. The dredging work will cause certain damage to the sewers. The use of crawler wheels can increase the contact area of the body and reduce the vibration, thus reducing the dredging work on the sewers, and extending the life of the sewer.

The electric retractable crawler wheel consists of two support wheels, one driven wheel, one motor, two gears, a chain and a support structure. The motor drives the intermediate gear to rotate, and the intermediate gear is driven by the chain to rotate near the end of the A collecting box end gear, and the end gear of the A collecting box is rotated coaxially with the corresponding crawler wheel, so that the crawler belt moves smoothly.

1.2 Control module

1.2.1 Machine workflow. The electrical control part is composed of a walking module, a cutter head rotation module, a telescopic rod module, an endoscope module and a power supply module, and the schematic diagram of the electrical control system is shown in Figure 5.
controlled by the remote control to extend or shorten to accommodate the pipe diameter. At the same time, the stepping motor drives the cutter disc to rotate, and the cutter head rotates to cut the sludge with the cutter disc, and the sludge is brought into the sludge tank A through the inner hole of the cutter disc through the internal scraper of the cutter disc. The DC motor drives the crusher to rotate and crush the bulk and compacted sludge block. The sludge then enters the spiral feeding tube driven by the DC motor, and is sent to the sludge tank B through the shaftless spiral blade for further processing.

1.2.2 Machine positioning and balance principle. "Speed sensor positioning method", that is the speed detector installed on the DC motor detects the instantaneous speed of the dredger in real time, and transmits the data to the single-chip microcomputer. The instantaneous displacement and total displacement are calculated by the single-chip microcomputer, and returned to the mobile phone Bluetooth. To achieve precise positioning of the dredging machine in the sewer. This way of working is not subject to the environment, the positioning is relatively accurate, and can be accurately positioned when the dredger is working. The balance part is detected by the gyroscope to tilt the body of the dredging machine. After the data is transmitted to the MCU, the MCU determines the balance condition and sends a command to control the track motor to achieve the balance of the body.

1.2.3 Principle of pipeline inspection. The endoscope is powered by the battery. The endoscope detects the sewer environment, and the image synthesis signal is wirelessly transmitted to the mobile phone Bluetooth to monitor whether the inner wall of the sewer pipe is broken or the sewer pipe is blocked. The endoscope detection module and the positioning module are combined to realize the sewage pipeline fault detection function.

2. Theoretical calculation and simulation analysis

2.1 The research of cutter material
By comparing several possible cutters in Figure 6[5], the 304 stainless steel plate has beautiful surface, high strength, high temperature oxidation resistance, easy plastic processing and good corrosion resistance. Although the price is high, its outstanding corrosion resistance is suitable for the sewer environment, so the 304 steel plate is finally used as the material of the cutter.

![Figure 6. The chart of Cutter material comparison](image)

2.2 The check of spindle performance
Since the size of the above cutter head directly affects the dredging speed of the work, the research on the required dimensions is carried out, and the technical parameters of each part are determined by comprehensive analysis as shown in Tables 1 and 2.
Table 1. The technical parameters of spoke panel cutterhead

| Outer diameter | Inner diameter | Thickness | Panel center angle | Spoke center angle |
|----------------|----------------|-----------|--------------------|-------------------|
| 550mm          | 490mm          | 25mm      | 50°                | 20°               |

Table 2. The technical parameters of the blade

| Length | Width | Maximum Height | Front Deflection | Rear Deflection |
|--------|-------|----------------|------------------|-----------------|
| 18mm   | 14mm  | 20mm           | 15°              | 5°              |

The motor power of the central axis of the cutter head is 72W, and its rotation speed is 20r/min. The torque received by the center shaft is:

\[ \text{Me}=9549 \times \frac{72W}{20\text{r/min}} \]

The torque stress is:

\[ \tau = \frac{\text{Me}}{W_t} = 175.08\text{MPa} \]

Based on the data, the central axis needs the \([\tau]=1821.61\), obviously \(\tau<[\tau]\), which meets the strength requirement. At the same time, the ANAYS simulation of the central axis strain is carried out. The simulation results show that the central axis deformation meets the coaxiality requirement. Figure 7 and Figure 8 are the results of the analysis of the spindle with ANSYS.

For the same reason, the strength and stiffness of the transmission shaft of the sprocket chain are analyzed:

\[ \text{Me}=9549 \times \frac{26.4W}{15\text{r/min}} \]

\[ \tau = \frac{\text{Me}}{W_t} = 11.41\text{MPa} \]

Based on the data, \([\tau]=1821.61\text{MPa}\), obviously \(\tau<[\tau]\), meets the strength requirement. According to the ANSYS strain simulation (Figure 9 and Figure 10), the drive shaft deformation meets the requirements.
3. Physical test

According to the three-dimensional virtual model and theoretical analysis, we made a physical prototype and conducted experiments, as shown in Figure 11 is the overall photo of the prototype. A series of tests have been carried out in the pipeline with sand, stone and their mixture, to simulate the actual situation of the sewer.

![Prototype](image)

Figure 11. The overall photo of the prototype

4. Conclusion

Three retractable track wheels placed on the outside of the desilting machine can adapt to different inner diameter sewage pipes. Combined with the silt collection and transmission device, the desilting machine can clean up the silt in the sewage pipes and collect it, so that people can carry out selective recycling treatment.

The equipment is designed to meet the needs of current urban sewer, and it can greatly reduce labor costs and operate costs by its high work efficiency and autonomy. The equipment is in line with current market demand, and it can better implement the idea of “Energy saving and emission reduction”. The equipment design is reasonable, easy to mass production, and has good application prospects and market prospects [6][7].

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