Structural Design of Tool Head of Pipe Dredging Device

Yufei Jia, Mengyu Shang, Haojun Sun, Chuang Pang, Junjie Liu and Xu Yang*
Shenyang Aerospace University, Shenyang 110136, China

*Corresponding author e-mail: 312428849@qq.com

Abstract. In the cold season, pipelines are prone to icing-induced clogging, causing great inconvenience to people’s production and life. To solve the icing-induced clogging of the pipeline, analysis was made on the reason why the original device fails to break the ice, to provide some guidance for conducting an innovative design of the cutter head of the device. Based on the actual needs for the cutter heads in the course of ice-breaking, a parallel inclined spherical rotary cutter head was proposed, and its 3D model created with the help of a modelling software. Through the operational and arc-traversing performance analyses of the cutter head, the relationship between the radial direction and the axial direction of the cutter head was constructed. The pressure relationship of the device was analysed. The conclusion was drawn as follows: the designed cutter head can improve the effectiveness of the device on ice-breaking and reduce the requirement for the structural intensity, providing a significant basis for the development of its physical prototype.

1. Introduction
In the cold season, when the pipe is frozen or the foreign matter is clogged, the pipe is mostly buried in the ground or in a place that is not easily in direct contact, it is relatively difficult to clean up the blockage [1]. Due to the different reasons of pipeline blockage, various types of cleaning devices still have certain limitations in practical applications, and there is still no good solution for pipe icing or hard blockage. In view of the harsh working environment of the pipeline cleaning device and the difficulty in direct intervention, the design of the cleaning device cutter head should meet the requirements of small size, light weight, stable operation and high reliability and so on. Therefore, we propose a parallel tilt ball rotary cutter head.

2. Original dredge device cutter work analysis
The existing rotary cutting type cleaning machine has a good application in the clearing of the drainage pipe, and can break the pipe blockage and achieve the purpose of dredging the pipe [2-4]. However, the drawback is that when the principle is applied to the clogging problem caused by icing or hard foreign matter, the linear velocity near the central axis of rotation is small, and it is impossible to effectively cut or break the obstacle in front, and the rear drive device is required to provide a strong thrust. Or a short-term strong impact will hinder the crushing, in order to ensure the advancement of the cutter head. Therefore, the required, power is relatively large, and the structural strength of the device is required to be high. At the same time, the device faces a long structural length and is difficult to cope with the problem of small radius turning, which imposes restrictions on the application of the device.
According to the analysis, the designed ice-breaking device cutter can adopt the method of rotary cutting to effectively break the ice, but it needs to effectively solve the shortcomings of low speed and unsatisfactory working effect near the center of rotation, so as to reduce the requirements on the driving device and structural strength, and realize the cutter head that is safe and effective for cornering work to improve its ability to break ice for various types of pipes.

3. Dredging device cutter head overall design
The current device head adopts a parallel tilt ball rotary cutter head design, and the design scheme (Fig. 1). The two identical ball cutter heads 5 are rigidly connected with the output shaft of the sub motor 4 to form a rotary cutting body, and the spindles of the cutting body are inclined clockwise by 15° to 20° with respect to the main shaft of the main motor 1, and then are biased toward the main motor main shaft. Move, keeping the outer surface of the head 5 is approximately tangent. The two rotating cutting bodies are rigidly connected to the T-shaped connecting frame 3 and rigidly connected with the output shaft of the main motor. The size of the T-shaped connecting frame is determined by other structures to meet the geometric requirements. The power of the sub motor 4 is input through the overcurrent slip ring 2. The above structure is integrated with the output shaft of the main motor, and realizes the revolving around the main axis while the excavating cutter head realizes the self-rotation cutting

![Figure 1. cutter head design plan](image)

Through the dynamic simulation of the design scheme through the 3D design software, the design effect of the rotary cutting can be achieved.

3.1. Work analysis

3.1.1. Work area determination. In order to illustrate the advantages of the double cutter head design, the double cutter head and the drill bit single cutter head are analyzed and compared (Fig. 2). The area where the two cutter heads block the phase in the pipeline is defined as the work area, and the area where the line speed of the same rotating body is less than 20% of the maximum line speed is defined as the invalid work area. Due to the different curvature radii between the inner and outer sides of the pipeline, the tension of the device on both sides of the neutral line is different, and the relative linear velocity of the invalid working area is too low to effectively cut the front occlusion [5-7]. The structure is required to provide extreme pressure along the speed direction to hinder the front. Crushing can ensure the continuous operation of the device.

![Figure 2. Work area analysis and driving force analysis](image)
In the bit-type single-blade, the ineffective working area accounts for 4% of the working area. The double cutter head makes a tilt of 15° to 20° outside the spindle, effectively avoiding the invalid working area. Therefore, in the working state, there is no invalid working area in the working area of the designed cutter head, and the working efficiency is higher.

3.1.2. Determination of driving force. When the two cutter heads are in the same working condition, the driving device gives the same driving force to the two cutter heads, and the driving force \( F \) acts on the rear end of the main motor. Since the pipeline working device adopts the cross universal joint shaft connection, the driving force direction along the tangential direction of the pipe center line.

The angle between the driving force and the speed direction of the cutter head in the pipe corresponds to the single cutter head and the double cutter head respectively. \( \beta_1 \) versus \( \beta_2 \). The angle is affected by the length of the two cutter heads and the radius of curvature of the pipe, but is limited by the size requirement of the bend. The size requirement is considered to be \( \cos \beta_1 = \cos \beta_2 \) in the working state.

The component force of the driving force along the speed direction of the cutter head reflects the effective force provided by the device for breaking ice, which affects the working efficiency of the cutter head. The component force corresponds to the two cutter heads respectively \( F \cos \beta_1 \) with \( F \cos \beta_2 \). The component force of the driving force along the radial direction of the pipe causes the cutter head to form a pressing friction or even a cutting with the inner wall of the pipe. Therefore, the component force should meet the mechanical performance requirements of the pipe wall design.

The working area of the two cutter heads is projected in the direction of the speed, and the projected area of the single cutter head is 
\[
A_1 = \pi \left( \frac{d}{2} \right)^2 \cos \beta_1
\]
and the double head projection area is 
\[
A_2 = \pi \left( \frac{d}{4} \right)^2
\]
Therefore, the average pressure of the two cutter heads giving the front blockage under the same driving force is:

\[
P_1 = \frac{F \cos \beta_1}{A_1} = \frac{4F \cos \beta_1}{\pi d^2}
\]
\[
P_2 = \frac{F \cos \beta_2}{A_2} = \frac{16F \cos \beta_2}{\pi d^2}
\]

Relative pressure:
\[
\frac{P_1}{P_2} = \frac{1}{4}
\]

It is calculated that under a given driving force, the double cutter head can provide a larger pressure than the drill type single cutter head, so that the double cutter head can reduce the structural strength requirement of the device when faced with the same working demand. Due to the existence of an ineffective working area for a single cutter head, the double cutter head has a more significant advantage.

3.2. Bending analysis

For the curve of different diameters and different angles faced by the device during the operation, whether the cutter head can effectively pass the curve will determine its adaptability [8]. Bend analysis of its cornering ability: In order to analyze whether the cutter head can pass the curve, a parametric analysis model is established, and the size needs to meet the size requirement. First, the tool head is simplified (Fig. 3), and the tool head forms a rotating body when working. The radius of curvature of the rotating body is smaller than the radius of the pipe, so that if the rotating body can pass the curve at its maximum contour, the cutting head can pass smoothly.
Since the cutter head keeps spiraling during work, it has an automatic centering capability. In order to ensure the stable advancement and effective cleaning of the cutter head in the pipeline, the tangential point of the two ball cutter heads at the front end of the rotating body and the center point of the rear end of the main motor are on the central axis of the pipeline. At any time, the rotating body is the same as the inner wall of the pipeline. Without interference, the rotating body can pass through the curve, that is, the entire design head can pass. Pipes use relevant design standards in the design process. Figure 3 shows the parametric analysis model. The dimensions of each part include: pipe inner diameter $-d$, pipe radius of curvature $-R$, axis offset distance $-\Delta$, axis length $-L$, main motor diameter $-d_{\text{the Lord}}$, sub motor diameter $-d_{\text{child}}$, the center of the circle $-\theta$, ball cutter radius $-r$.

Among them, in order to ensure the effectiveness of the work, the radius of the ball cutter head ($r$) should satisfy:

$$ r = \frac{d}{4} $$

Axis offset distance ($\Delta$) Determined by other structures, the size is:

$$ \Delta = \left( R + \frac{d}{2} \right) \left( 1 - \cos \frac{\theta}{2} \right) $$

When the cutter head is in the middle of the curve, the dimensions such as length and diameter should satisfy the following relationship:

$$ \begin{align*}
L &= 2 \left( R + \frac{d}{2} \right) \sin \frac{\theta}{2} \\
d_{\text{the Load}} \leq \frac{d}{2} \\
\frac{\Delta}{2} + R + \Delta &\leq \frac{d}{2} \\
d_{\text{child}} \leq \frac{d}{2} \\
\end{align*} $$

4. Conclusion
(1) By establishing an analytical model, the geometric relationship of the dimensions of each part of the double cutter head is established, which satisfies the relationship between the radial direction and the axial direction, and the cutter head can smoothly pass the corner of the curve.

(2) Do work analysis on the double cutter head, reduce the reaction force on the machine body, reduce the structural strength of the device, and improve the work efficiency.

(3) The design of the cutter head device improves the ability to break ice, and has good application value for the development of physical prototype.

Acknowledgments
This work was financially supported by National College Students’ innovation and entrepreneurship training program (No. 110418127) fund.

References
[1] Dianjun Wang, Runping Li, Guangming Huang. Research progress of pipeline robots [J].
Machine Tool Hydraulics, 2008 (04): 185-187.
[2] Weiyuan Zhou, Fei Fang, Lijian Chen, Shou Mao, Ming Xia. Four-way walking intelligent robot system for underground pipelines [J]. Sensors and Microsystems, 2017, 36(09): 73-76.
[3] Tao Yu, Huanpeng Guo, Xin Fan, Lingzan Kong. Design and optimization of a new air conditioning ventilation pipe cleaning robot [J]. Mechanical design and manufacturing, 2019 (04): 248-250+255.
[4] Jianqiang Li, Wei Lu, Guangyi Zhao. Application of rotary cutting type cleaning machine in drainage pipe dredging [J]. Water supply and drainage, 2014, 40 (03): 86-89.
[5] Lu Yu, Lei Liang, Wei Zhu. Development of pipeline robot for quality inspection of steel pipe [J]. Mechanical Engineer, 2018 (07): 24-26.
[6] Chenzhong Wang, Ting Wang, Jun Liu, Chaolong Zhang, Shaogang Hu. Research on driving characteristics of differential adaptive pipeline robot [J]. Mechanical Transmission, 2017, 41(01): 160-165.
[7] Yaoyong Xue, Jizhong Zhang, Lei Zhang. Design and obstacle analysis of automatic adaptation mechanism for pipeline robots [J]. Manufacturing Automation, 2018, 40 (06): 23-26.
[8] Fengping Xu, Zongquan Deng. Study on the pass ability of pipeline robots in corners [J]. Robotics, 2004 (02): 155-160.