NEW PIPELINE IN-LINE INSPECTION TECHNOLOGY BASED ON SELF-PROPELLED

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Abstract

The in-line inspection tool has no power since there is no medium in the new pipeline. Aiming at the problem of the difficulty of detecting the newly-built pipeline, a self-propelled detector with an autonomous power system is designed.

By controlling the posture of the self-propelled robot, the walking scheme is designed. To ensure the smooth operation of the self-propelled robot in the pipe, the robot runs at a constant speed in the horizontal pipe section, and the upward slope pipe section increases the traveling power, while the downslope pipe section is the opposite. Designed pipeline climbing experiment and loop experiment to ensure the stability and safe operation of the robot in the actual project. Experiments have proved that a self-propelled robot has 90°climbing ability and can pass the bend effectively. The self-propelled robot equipped with the caliper sensor was successfully applied to the 157km new pipeline. The detector ran smoothly, and the customer accepted the excavation verification results. A new detection method is provided for the newly-built pipeline to ensure safe operation.

Keywords: New pipeline detection, Self-propelled detector, Geometric deformation detection, Pipeline mapping, Posture control

Introduction

At present, the detection of pipelines before commissioning mainly relies on air or water as power, which will increase the cost. Moreover, due to the compressibility of air, the operation of the inspection tool is unstable, so that the accuracy of the detection result cannot be guaranteed. In the history of R&D of self-propelled detectors, there are some references in the international scope as follows. Scholl has developed a walking robot, which can walk in a short-distance pipe with an inner diameter greater than 30mm [1]. M. Tawakoni designed a street lamp cleaning robot with a parallel structure [2]. By controlling the two drives to move at different speeds, Jeon and others can realize the robot inspect the T-shaped pipe [3]. Fykuda T and others designed a bridge rope crawling robot with obstacle avoidance function [4]. Omori et al. designed a pneumatic telescopic pipe detector, which can operate at a slower rate in the bend and U-shaped pipe [5]. Yoon developed a pneumatically driven pipeline detector, which runs in a pipeline with an inner diameter of 100-300mm [6].

In this paper, the traveling plan of the self-propelled robot is designed, combined with the actual working conditions of the pipeline, the expected indicators of the robot are put forward, and the mechanical structure, power mechanism, support unit, and other key mechanisms are analyzed and designed, and the overall structure design of the robot is completed. Design this self-propelled robot equipping detection system to realize real-time online detection of newly-built pipelines, and provide a new detection method for pipeline inspection before commissioning to ensure safe operation.

1. Self-propelled robot structure

1.1. *Structure introduction*

The self-propelled robot adopts a six-wheel and six-motor parallel drive mode, with a compact structure and large driving power to ensure its smooth operation in the pipeline.

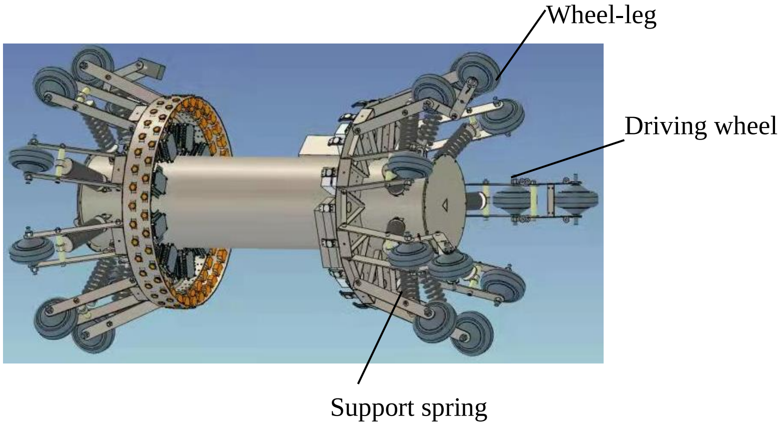


Figure 1. Self-propelled robot mechanical structure

The main structure of the self-propelled robot is an organic unit, which includes support springs, driving wheels, wheel legs, etc. It can cushion impact and improve operational stability.

1.2. *Self-propelled robot travel control system*

The self-propelled robot has a good passing ability, can run up and down with the pipeline trend during operation, and has good adaptability to a variety of environments. The motor control system detects the posture angle of the robot through the IMU sensor and adjusts its operation mode according to the real-time posture to ensure its smooth operation.

Posture matrix C_b^n：

$$C_b^n = \begin{bmatrix} T_{11} & T_{12} & T_{13} \\ T_{21} & T_{22} & T_{23} \\ T_{31} & T_{32} & T_{33} \end{bmatrix} = (C_n^b)^{-1} = (C_n^b)^T = T \quad (1)$$

The posture angles are calculated as follows：

$$\theta = \sin^{-1}(T_{32}) \quad (2)$$

$$\gamma = \mathrm{tg}^{-1}(-\frac{T_{31}}{T_{33}}) \quad (3)$$

$$\psi = \mathrm{tg}^{-1}(-\frac{T_{12}}{T_{22}}) \quad (4)$$

The main value range of pitch angle is -90° to 90°, roll angle's main value range is -180° to 180°; heading angle range is 0° to 360°. After the robot enters the motion state, the projection of the relative acceleration vector of the navigation coordinate system relative to the earth coordinate system on the navigation coordinate system is:

$$\vec{a}_{en}^{n} = \vec{a}_{ib}^{n} - (2\vec{\omega}_{ie}^{n} + \vec{\omega}_{en}^{n}) \times \vec{V}_{en}^{n} + \vec{g}^{n} \quad (5)$$

Based on the robot's posture and acceleration information, the power control method is reasonably distributed to ensure smooth operation, and the climbing and braking functions are activated on the uphill and downhill pipelines.

2. Self-propelled robot performance verification

2.1. *Passing ability test*

The total length of the loop pipeline used in the experiment is 66 meters, including four 3.5D bends, to verify the robot's passing ability and continuous operation ability. The average speed of the robot is 1m/s and the mileage is 36 kilometers.

(a) Loop experimental site

(b) The test process

Figure 2. Passing ability experiment

2.2. *Climbing test*

Put the robot into the experimental pipe, placement angle is from 0 to 90°. Start the robot, and record the experimental data of 10°, 20°, 30°, 45° in the pipe, as shown in Table 1.

Table 1. Test data

Slope	Drive current	Brake current	Uphill speed	Downhill speed
（°）	（A）	（A）	（m/s）	（m/s）
10	14	4.5	1.6	0.2
20	16.5	7.6	1.6	0.25
30	27	12	1.6	0.4
45	36	15	1.6	0.45

(a)30° (b)45° (c)90°

Figure 3. Climbing test

Experiments show that the robot can stabilize the speed in both the uphill pipe section and the downhill pipe section to ensure stable operation, what is more, it has a 90° vertical pipe section climbing ability.

2.3. *Case study*

Φ762mm self-propelled pipeline detector carries caliper sensor, video recording system, lighting system, and IMU. The IMU can completely describe the geographic coordinate direction of the pipeline, and its acceleration sensor and gyro sensor information can be provided to the travel control system to control the posture of the detector. The running speed is shown in Figure 4.

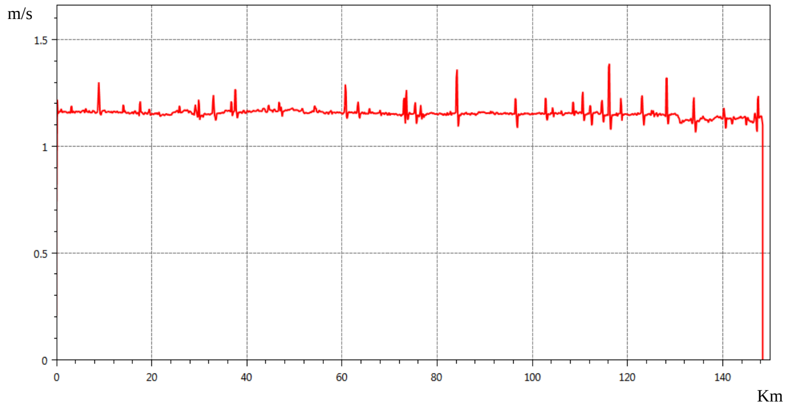


Figure 4. Speed

The speed of the detector is stable at 1.5m/s and the mileage is 151km. The intelligent power management system reasonably allocates power control methods according to the running status of the detector. Maintain a constant speed in a straight pipeline. Start the second auxiliary power wheel when going uphill, and increase the instantaneous power to increase the climbing ability. When going downhill, the motor is switched to the power generation state, which acts like an electric brake. The motor control system can judge the horizontal tilt angle and rotation posture of the detector through the IMU, and adjust the motor according to the posture so that the motor runs in a stable differential operation mode to ensure the smooth running of the detector. The geometric deformation detection probe carried by the self-propelled detector can identify the pipe body features such as pipe spiral welds, valves, and tees. As shown in figure 5.

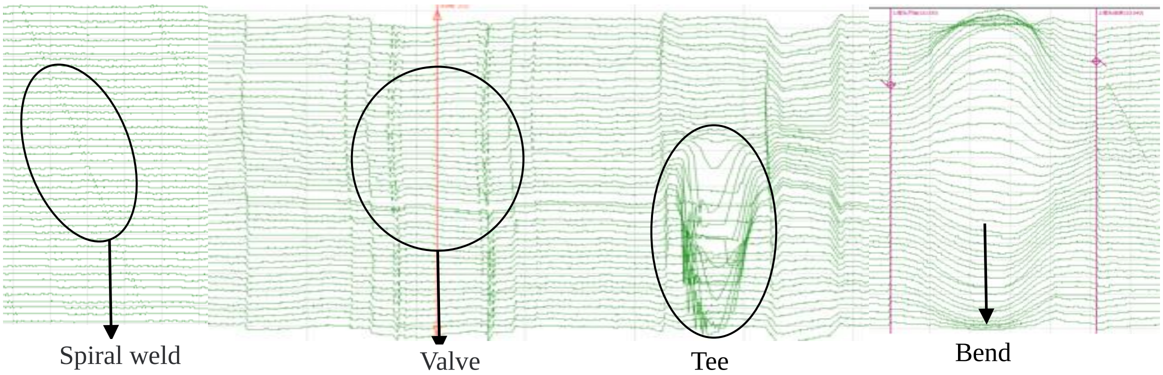
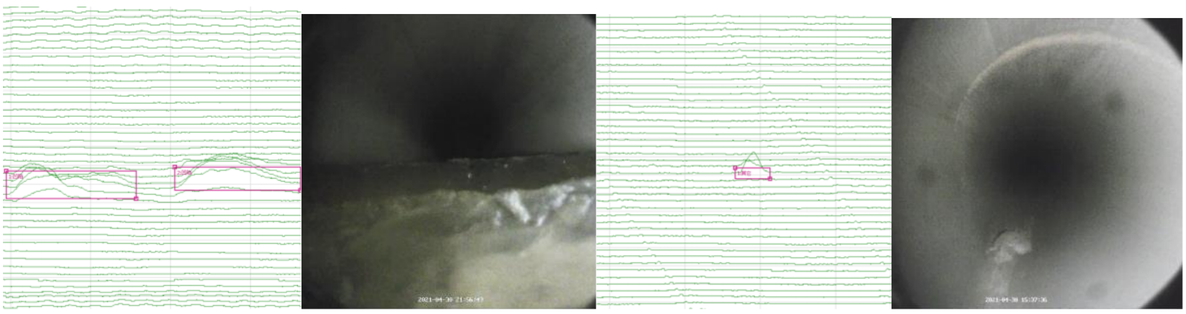


Figure 5. Pipeline feature signal

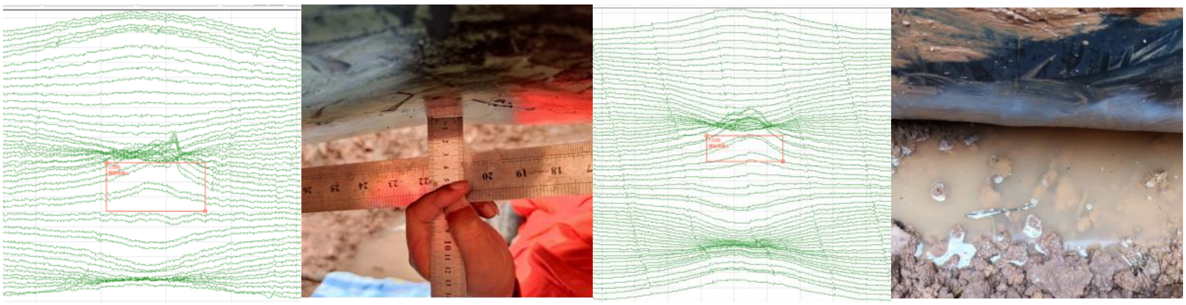
The detector carries a video recording system to record the situation in the pipeline. The dent signal may be caused by deformation or a foreign body. By comparing the detection signal with the video information, the dent signal caused by a foreign body in the pipeline can be distinguished.



(a) Foreign body signal1 (b)Water (c) Foreign body signal2 (d) Cement block

Figure 6. Foreign body signal

Figure 6 shows the signal of foreign matter and the image recorded by the video recording system. The pipeline deformation signal and the actual situation of the pipeline are shown in Figure 7.



(a)Dent1 (b) Verification 1 (c)Dent 2 (d) Verification 2

Figure 7. Dent signal and verification

The two dents are located at the mileage of 136184.2m and 58877.4m respectively. The actual depth of dent1 is 27mm, the detection result is 26mm, and the accuracy is 96%. The actual depth of dent2 is 25mm, the detection result is 24mm, and the accuracy is 96%.

Excavation verification shows that the detector can effectively inspect the 151km new pipeline with a stable speed and high accuracy.

3. Conclusion

This article introduces a pipeline self-propelled robot. It can record its posture information, control the power system to deal with uphill and downhill, ensure stable running speed, and have the ability of 90° climbing and downhill.

It can realize geometric deformation detection and mapping before commissioning. In addition, the robot can also be equipped with stress detection probes, crack detection probes, etc., to achieve a comprehensive inspection of new pipelines.

References：

[1] Scholl K U , Kepplin V , Berns K , et al. An articulated service robot for autonomous sewer inspection tasks[C]// IEEE/RSJ International Conference on Intelligent Robots & Systems. IEEE, 1999.

[2] Mahmoud Tavakoli, M.R. Zakerzadeh, A hybrid pole climbing and manipulating robot with minimum DOFs for construction and service applications[J]. Industrial Robot, 2005, 32(2):171-178.

[3] W Jeon, I Kim, J Park,etc. Design and control method for a high-mobility in-pipe robot with flexible links[J]. Industrial Robot: An International Journal, 1973.

[4] Fukuda T , Hosokai H , Otsuka M . Autonomous pipeline inspection and maintenance robot with inch worm mobile mechanism[C]// IEEE International Conference on Robotics & Automation. IEEE, 2003.

[5] Omori H , Hayakawa T , Nakamura T . Locomotion and Turning Patterns of a Peristaltic Crawling Earthworm Robot Composed of Flexible Units[C]// Intelligent Robots and Systems, 2008. IROS 2008. IEEE/RSJ International Conference on. IEEE, 2008.

[6] Yoon K H , Park Y W . Pipe inspection robot actuated by using compressed air[C]// 2010 IEEE/ASME International Conference on Advanced Intelligent Mechatronics. IEEE, 2011.