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Overview of Pipeline Inspection Robots

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Abstract: Pipelines are widely used in our daily life and industrial production, in order to solve the ensuring problem of pipeline failure, many kinds of pipeline inspection robots have appeared, and nowadays, pipeline robots have been widely used in various pipeline inspection and repair. This paper mainly discusses the importance of pipeline inspection robots in various pipeline fields, describes the technical characteristics of pipeline robots at home and abroad in recent years, and puts forward suggestions for the future development of pipeline robots in view of the existing problems, which is of reference significance for the future development.

Keywords: A plumbing robot; Tube inspection; Developing the status.

1. Introduction

In modern society, pipelines have penetrated into many corners of our lives, providing convenience for the transmission of energy and materials and bringing great economic benefits. However, at the same time, problems such as aging, corrosion and clogging of pipelines also come along. Due to the special location of many pipelines, human beings cannot have direct access to them, which brings great challenges to pipeline inspection and maintenance work. Traditional inspection and maintenance methods, such as excavation and random sampling, are not only labor intensive but also inefficient.

Since the beginning of the 1950s, since the domestic and foreign research on pipeline robots, pipeline robots have begun a rapid development, and now pipeline robots have been widely used in gas transmission, water diversion, petrochemical and thermoelectric steam transmission and other areas of pipeline inspection and maintenance. The research and application of pipeline robots can not only greatly reduce the workload of pipeline inspection and maintenance, reduce the labor intensity of workers, improve the efficiency of pipeline inspection and maintenance, but also reduce the cost of inspection and maintenance.

2. Classification of pipeline robots

According to the moving mechanism, the pipeline robots can be divided into roller mobile, Tracked mobile, peristaltic mobile, and liquid-driven, etc [1].

2.1. Roller mobile pipeline robot

Roller mobile pipeline robots use rollers as a driving mechanism and move by motor. Roller drive has advantages such as high power transmission efficiency and stability of operation, which has become the main driving mode of pipeline robot [2].

Roller mobile pipeline robots are supported straight-in type and screw-driven type. Supported straight-in pipeline robot, as shown in Fig. 1, the axis of the pipeline robot roller is perpendicular to the centerline of the pipeline, the forward direction of the roller is the same as the direction of the pipeline, and it moves along the axis of the pipeline under the action of the driver [3].

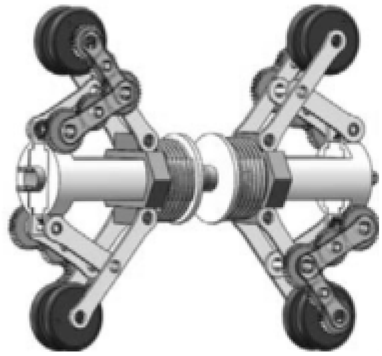

Figure 1. Supported straight-in pipeline robot

Spiral-driven pipeline robot, as shown in Fig. 2, the axis of the robot's rollers is not perpendicular to the axis of the pipeline, and there exists a certain angle a (helical climb angle, 0<a<90°), the helical climb angle provides axial and circumferential partial velocity for the robot to move forward, and it advances along the pipeline in the putative form of a helix under the action of the actuator [3].

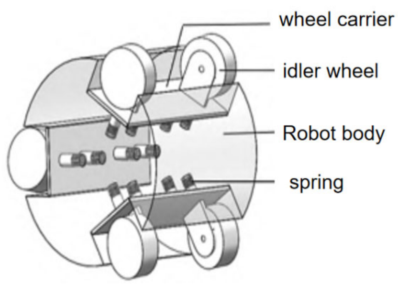

Figure 2. Screw-driven pipeline robot

2.2. Tracked mobile pipeline robot

A tracked mobile pipeline robot uses tracks as its traveling mechanism and moves using motor drives. Tracks provide stable support for the robot and increase the robot's ability to pass. Commonly, tracked pipeline robots can be categorized into double-tracked and triple-tracked depending on the number of tracks.

Dual-tracked pipeline robot, as shown in Fig. 3. The double-tracked pipeline robot has a smaller structure and better flexibility, but it can't stick to the inner wall of the pipeline, and its movement in the pipeline is unstable and prone to tilting, and it's not suitable for occasions where the slope of the pipeline is large [4].

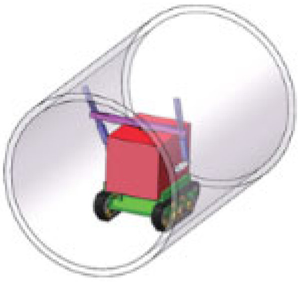

Figure 3. Dual tracked pipeline robot

A three-track pipeline robot, as shown in Fig. 4. The three-track robot can adapt itself to the size of the pipeline by adjusting the device, so that the three tracks closely fit the inner wall of the pipeline to generate a large enough adhesion force, and ultimately provide greater forward momentum for the robot movement under the action of the actuator [5].

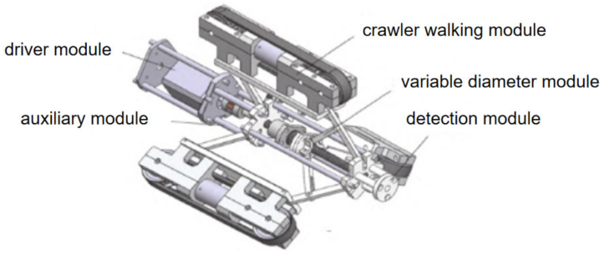

Figure 4. Three tracked pipeline robot

2.3. Peristaltic mobile pipeline robot

Peristaltic mobile pipeline robots are modeled after the peristaltic forward and backward movements of reptiles crawling on the ground. Peristaltic pipeline robots are highly redundant degrees of freedom motion robots that avoid the disadvantage of wheeled or tracked robots that cannot continue working after they have rolled over on their side [6].

2.4. Liquid-driven pipeline robot

Fluid-driven pipeline robots utilize the pressure difference drive of the fluid to achieve motion in a pipeline filled with a medium, as shown in Fig. 5. Roller-type and crawler-type pipeline robots are more difficult to control the traveling speed and are prone to large fluctuations. In addition, they are limited in carrying energy, making it difficult to work for long periods of time inside pipelines. These problems severely limit the working time and working distance of pipeline robots. Fluid-driven pipeline robots, on the other hand, utilize the pressure of the fluid to achieve the walking function. This design makes it easier to accurately control its speed and enables it to travel stably, thus improving the overall performance of pipeline robots [7].

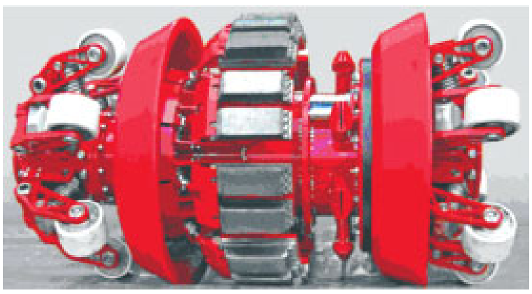

Figure 5. Liquid-driven pipeline robot

3. Current Status of Research on Pipeline Robots

3.1. Current status of pipeline robot development abroad

Foreign research on pipeline robots can be traced back to the 1950s. With the development of industrialization in the West, the demand for inspection and maintenance of oil and gas pipelines gradually increased, and the demand for in-pipe robots also grew rapidly. J. VERTUT of France developed a wheel-legged in-pipe walking mechanism model IPRIV in 1978, which realized autonomous walking in the pipeline despite its simple structure and single function, and had a profound impact on the development of pipeline robots. In the 1870s, the United States rapid development of pipeline transportation, greatly enhancing the United States of America on the pipeline inspection equipment research needs. 1962, the United States Knapp and Girard developed a robot for pipeline cleaning "pipeline pig". PIG is the most representative of the early pipe cleaning and inspection equipment, there is no autonomous drive capability, its forward power from the head and end of the fluid pressure difference, without the need for trailing cables or carrying batteries to drive, once can walk several hundred kilometers [8].

Islas-Garciaea et al. at the National Polytechnic Institute of Mexico developed a bionic type pipeline robot [9], as shown in Fig. 6. The robot uses rollers as a walking mechanism and is mainly used to detect and analyze the condition of underground drainage pipes in different highways in Mexico.

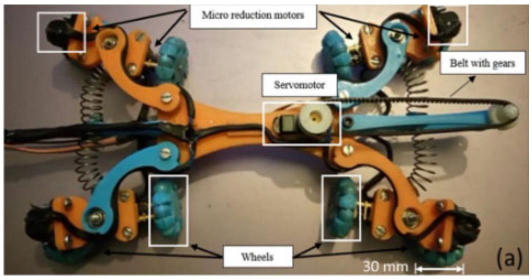

Figure 6. Roller mobile pipeline robot

A peristaltic drive mechanism for narrow pipes was designed by Tomonari Yamamoto et al. in Japan, as shown in Fig. 7. The robot achieves rapid motion through narrow ducts by a unique dual-chamber structure, and the mechanism achieves smooth bi-directional peristaltic motion by a combination of expandable silicone rubber and coil springs, which can be fully controlled by only two air supply lines [10].

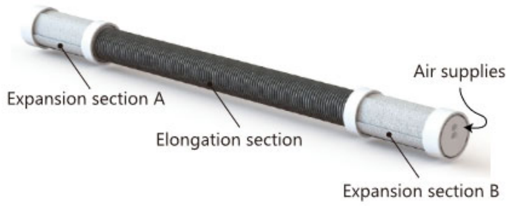

Figure 7. Peristaltic pipe drive mechanism

H. Torajizadeh, et al. at Kharazmi University, Iran, designed a spiral type of pipeline robot as shown in Fig. 8. The robot is capable of moving through any pipe in a predefined range of diameters at a variable helix angle and reporting any required data inside the pipe with the help of an installed camera [11].

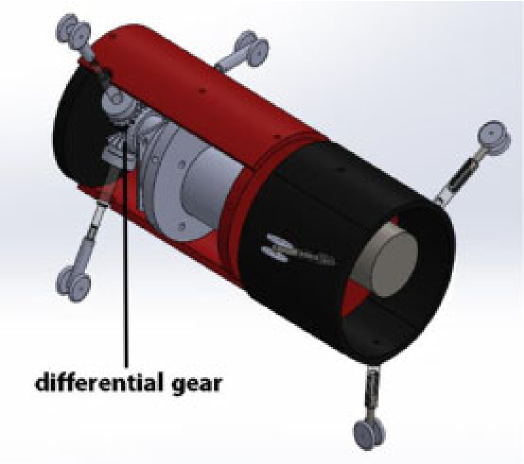

Figure 8. Spiral pipeline robot

3.2. Current status of domestic development of pipeline robots

Domestic research on pipeline robots started late, and the development of pipeline robots still has a certain gap compared with developed countries. However, with the rapid development of China's industry, as well as the importance of the field, there has been considerable progress.

In 1989, Deng Zongquan and others from Harbin Institute of Technology were the first to carry out research on mobile robots in the pipeline, which was mainly used for automated inspection of large-caliber pipelines [7]. Shanghai Jiao Tong University, Shanghai University and a large number of colleges and research institutions in the field of pipeline robotics also have more research results.

Li Yin et al. from Shaoguan College designed a snake-shaped pipeline robot [6], as shown in Fig. 9. The robot advances through the motion of peristalsis, a peristaltic cycle advances 0.145m, while using 57 two-phase stepper motors and STM32 control, which is able to realize the pipeline detection and unclogging work.

Figure 9. Snake pipeline robot

A fluid-driven pipeline robot was designed by Tao Shi et al. from Kunming University of Science and Technology, as shown in Fig. 10. The robot is a modular chain pipeline robot, which solves the problems of traditional fluid-driven robots with large structural volume and unpredictable friction main force[12].

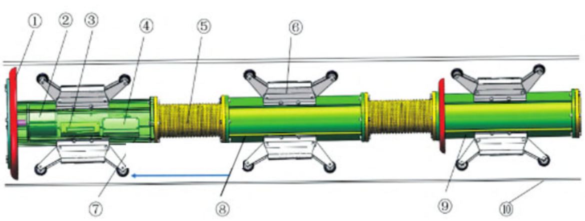

Figure 10. Fluid-driven pipeline robot

Liu Qingyou et al. from Southwest Petroleum University designed an active spiral-driven pipeline robot [13], as shown in Fig. 11. The robot consists of guide wheels, drive wheels, planetary gears, motors and other components, and STM32 is used as the central control unit. This pipeline robot solves the problems of passive spiral pipeline robot's small traction force and low mechanical transmission efficiency.

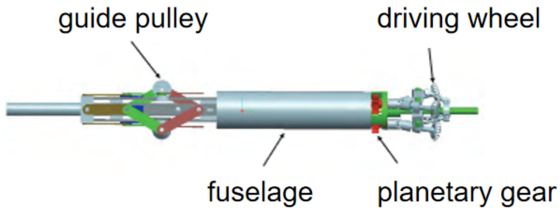

Figure 11. Active screw-driven pipeline robot

4. Problems with Pipeline Robots

1) Adaptation and obstacle-crossing ability problem. In reality, pipelines have various shapes, such as reducers, bends, "T" pipes, etc. At the same time, there may be debris or defects in the pipeline, which may affect the work of pipeline robots. Therefore, how to improve the adaptability and passability of pipeline robots in various complex pipeline environments is an important direction for current and future research.

2) Energy supply problem. Currently, pipeline robots mainly use electricity as their energy source. For cable-trailing pipeline robots, when the working distance is far away or the internal environment of the pipeline is uneven, the friction between the cable and the pipeline wall increases and the length of the cable limits the working distance of the robot. For cable-less pipeline robots, batteries are generally used as the storage energy, which is limited by the size of the pipeline and the machine itself, the energy it carries is limited, also limiting its working distance.

3) Signal transmission problem. Pipeline robots in the pipeline inspection and maintenance need to timely contact with the outside world, there are two main signal transmission methods, one is dragging the communication cable, the other is wireless signal transmission. Robot communication by dragging the communication cable in long-distance operation cable in the pipeline resistance will become very large, hindering the work of the robot. The wireless communication method is limited by the working environment of the pipeline robot, and the signal may be weakened by the medium in the pipeline, or by the pipeline itself, or by the environment outside the pipeline.

4) Reliability issues. Pipeline robot due to its special working environment, if the robot fails in the pipeline or gets stuck in the pipeline and clogs the pipeline, it may cause greater economic losses.

5. Conclusions

After decades of development, pipeline robotics technology has gradually matured and is transitioning from experimental research to practical applications. With the continuous progress of science and technology, as well as more and more researchers' attention and investment in pipeline robotics, future pipeline robotics research will mainly focus on the following aspects:

1) Intelligent: future pipeline robots will be more

intelligent, capable of autonomous perception, decision-making and execution of tasks, with greater autonomy and adaptability.

2) High performance: In order to adapt to more complex and harsh pipeline environments, pipeline robots need to have higher performance and greater adaptability. Future pipeline robots will use more advanced sensors, controllers and actuators to achieve more efficient and accurate detection and operation.

3) Miniaturization: In order to access smaller pipelines, such as urban drainage pipes and oil and gas pipelines, future pipeline robots will be more miniaturized. Miniaturized pipeline robots can more easily enter small spaces for finer inspection and maintenance.

4) Safety: The safety of pipeline robots is an important area for future research. Future pipeline robots will utilize safer and more reliable designs and technologies to ensure that they perform their tasks without causing damage to people and the environment.

5) Remote control: Future pipeline robots will pay more attention to the development of remote control technology. Through remote control technology, operators can control pipeline robots in a safe and comfortable environment, realizing more efficient and safer operations.

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