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Research Status and Technical Difficulties of Pipeline Robot

Zhizhong Lv, Lang Xu

School of Mechatronic Engineering, Southwest Petroleum University, Chengdu 610500, China

Abstract

With the development of economy and social progress, the development of China's industrial sector is booming, and the construction of oil and gas pipelines is speeding up. The inspection and maintenance of pipelines has become the current research focus. Through the analysis of the working environment and characteristics of the existing six categories of pipeline robots, the current research status of pipeline robots is systematically expounded, and the current research difficulties of pipeline robots are summarized. The summary and analysis contents have certain reference value for the future research of pipeline robot.

Keywords

Pipeline Robot; Research Status; Research Difficulties.

1. Introduction

In recent years, with the economic development and social progress, China's industrial sector has developed vigorously, the people's living standards have been increasing, and the demand for energy has been increasing. In order to cooperate with the expansion of China's oil and gas market, the construction of oil and gas pipeline networks has also made certain achievements. By the end of 2021, the cumulative mileage of oil and gas long-distance pipelines in Chinese Mainland has reached 150000 kilometers, including about 89000 kilometers of natural gas pipelines, about 31000 kilometers of crude oil pipelines, and about 30000 kilometers of product oil pipelines [1].

During the long-term use of oil and gas pipelines, the internal media will inevitably cause erosion and corrosion to them, resulting in internal defects of the pipeline, and eventually lead to oil and gas leakage of the pipeline, pollution of the environment, and even explosion, damage to normal production and life, endanger people's personal safety, and cause property losses. According to the statistics of the Hazardous Materials Safety Management Committee and the United States Department of Transportation, 894 accidents related to the failure of oil, natural gas and hazardous liquid pipelines occurred in the United States alone between 1995 and 2014, resulting in 360 deaths and 1368 injuries [2]. Therefore, regular inspection and safety maintenance of the pipeline, early detection of hidden defects in the pipeline, and timely elimination of potential safety hazards are crucial in the construction of oil and gas pipeline network.

Pipeline robot, as a special robot with high degree of intelligence, can carry cameras, sensors, operating tools, etc. into the pipeline and complete relevant work as required. For example, carry a camera to take pictures of the inner wall of the pipeline, and then transmit the results to the ground. The staff will use the received graphic data to carry out digital image processing on it by the computer, and then judge whether there is any damage inside and how much damage is. At the same time, get the location of the damage, accurately locate the location of the need for maintenance, and timely assist the maintenance personnel in pipeline maintenance, reduce the workload and reduce maintenance time, Ensure the safe operation of the pipeline.

2. Development Status of Pipeline Robot

Pipeline robot is a product that was born with the construction of pipeline network in the last century and serves for the detection and maintenance of oil and gas transportation pipelines. It was initially studied by the United States, Britain, Japan, Germany and other countries. The most representative is a pipeline detection and cleaning equipment - PIG [3], which has no power source and relies on the medium pressure difference at both ends of the robot in the pipeline to provide walking power. Since the 1970s, the rapid development of economic and scientific level in developed countries has accelerated the research of pipeline robots. In the 1990s, with the emergence of communication technology, microprocessors and artificial intelligence, it has provided more comprehensive functions and stable control force for the operation of pipeline robots in the pipeline, and enhanced the stability of pipeline robots. Since its birth, pipeline robots have a wide variety, different shapes and different functions. According to different mechanical structures, they can be divided into 6 types as shown in Figure 1: medium pressure differential pipeline robots, wheeled pipeline robots, tracked pipeline robots, spiral pipeline robots, walking pipeline robots and bionic pipeline robots [4,5].

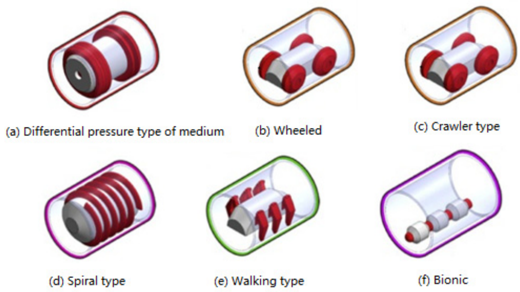

Figure 1. Pipeline robot classification

2.1. Research Status of Pipeline Robot

German ROSEN is a leading global supplier of cutting-edge solutions in all fields of the integrity process chain. Its product pipeline pig can operate in high-speed flowing fluid, as shown in Figure 2. It provides complete multi-physics all-round detection such as magnetic flux leakage detection, optical detection, ultrasonic detection for oil and gas pipelines.

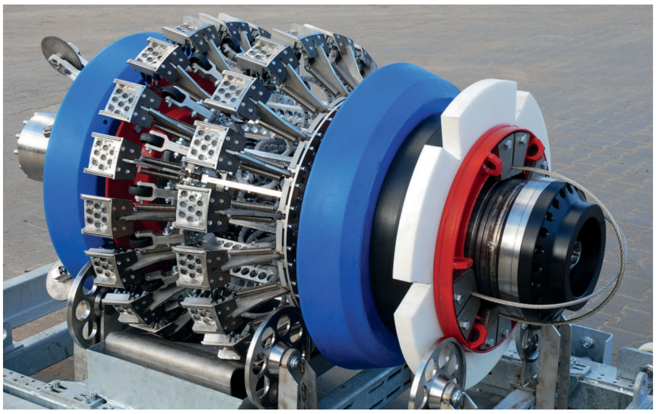

Figure 2. ROSEN Pipeline Pig

S. G. Roh of Sungkyunkwan University in South Korea and others have jointly developed MRINSPECT series of pipeline robots [6,7]. They have the ability to pass through elbow pipes, and also have the ability to turn pipes. They can choose to turn during driving, and pass through urban gas pipelines with branch pipes. MRINSPECT IV in this series of robots, as shown in Figure 3 below, is mainly composed of body frame, drive module and electric coupler (CCD). The radial dimension of the robot is 85-109 mm, and the axial dimension is 150 mm. Relying on the body weight of 0.7 kg, it can generate 9.8N traction force and 0.15 m/s travel speed. Ho

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Moon Kim et al. applied a multi-axis gear differential mechanism to MRINSPECT VI [8], which solved the problem that the speed of the robot wheels could not be accurately controlled during the rotation of the inner wall of the pipe, resulting in the uncoordinated rotation of the wheels, thus consuming unnecessary energy and causing irreparable damage to the robot.

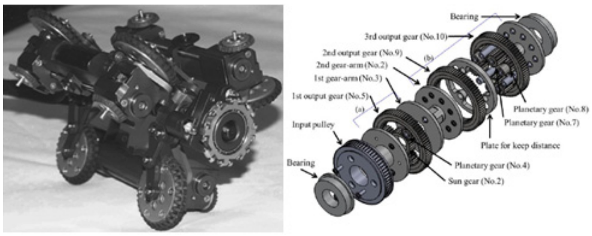

Figure 3. Pipeline robot of Sungkyunkwan University in South Korea

As shown in Figure 4, it is a pipeline detection robot with a linkage mechanical clutch developed by Young-Sik Kwon and Byung-Ju Yi of Hanyang University in South Korea [9]. The total length of the body is 122 mm, the minimum external diameter is 90 mm, and the maximum extension is 110 mm. The weight of the robot is 189 grams. The robot operates in a pipeline with a pipe diameter of 100 mm at a speed of 14 cm/s. The robot is small and flexible. The experimental results show that it can smoothly pass through the 90-degree elbow. It can detect the pipeline through its own lighting system and camera, and can successfully recover it through the external control system. However, the tractive force of the robot is too small for external power supply, so the detection distance is limited, and it is not suitable for the detection of long oil and gas pipelines.

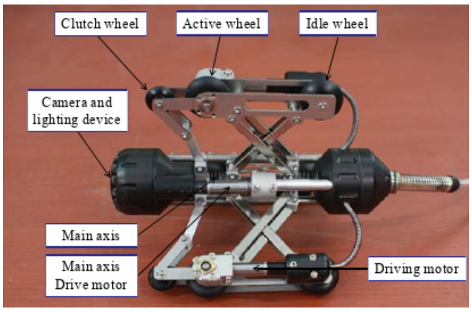

Figure 4. Pipe robot of Hanyang University in South Korea

Dimitris Chatzigeorgiou, Kamal Youcef-Toumi and Rached Ben-Mansour of Massachusetts Institute of Technology jointly developed a wheeled support pipeline robot with special structure [10,11] in 2014. As shown in Figure 5, the robot's feeding gear system is not a traditional triangular support, but is designed with reference to the independent suspension system of the flat car, which makes the robot have a small eccentricity in the process of obstacle surmounting and improves its obstacle surmounting ability. A new detection method is proposed in the design of the robot, which is based on the principle of recognizing local pressure gradient and keeping relatively insensitive to the fluid medium in the pipeline. This method has wide applicability in pipeline detection.

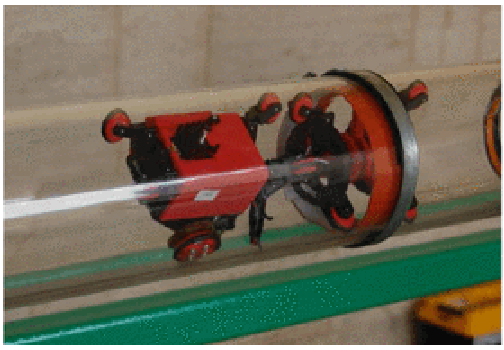

Figure 5. MIT wheeled pipeline robot

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As shown in Figure 6, in 2013, Atushi Kakogawa team of Ritsumeikan University in Japan developed a tracked pipeline robot based on the under-driven parallelogram crawler module [12,13]. Its biggest feature is that it is installed with three under-driven parallelogram crawler modules, which automatically changes its shape into a quadrangle when encountering obstacles. In order to complete this series of operations, the author designed a differential mechanism, The design method of output ratio of differential mechanism is determined. The drive module of the robot is connected with two independent connecting rods to support and adjust. When encountering special obstacles, such as variable diameter pipes, the drive module of the robot can shrink into a cone and cross the pipe.

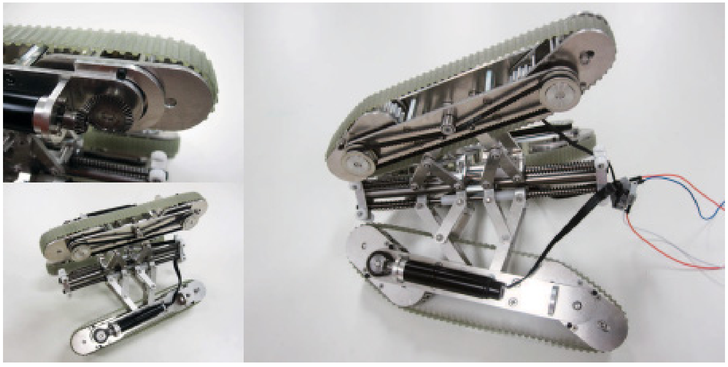

Figure 6. Japan's Ritsumeikan robot

Atsushi Kakogawa team of Japan's Ritsumeikan University has developed a series of spiral pipe robots for small and medium-sized pipes (Figure 7) [14]. The overall size of the robot's fuselage is at least 109mm, and it can expand to 129mm at most. The axial length is 175.8mm, the helix angle is 10 degrees, and the total weight is 0.7kg. The maximum travel speed in the pipeline is 500mm/s. The robot has three motion modes: screw drive mode, steering mode and rolling mode. In the spiral mode, the motor drives the head to drive the robot forward and backward in the pipeline; Steering mode: the steering motor set in the middle module drives the front head to rotate to realize independent steering. This mode is used for branch pipes or elbows with small curvature radius; In the rolling mode, the robot can change its navigation direction in the pipe that cannot be turned, for example, in the straight pipe or at the top of the "T" in the T-shaped branch. The structural stability of the robot needs to be improved.

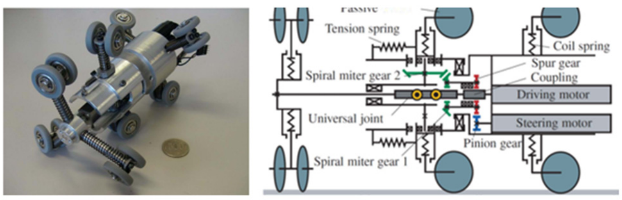

Figure 7. Steerable spiral pipe robot

Xiao Xiaohui, Chen Xiao and others from Wuhan University designed an adaptive supporting pipeline detection robot for the detection requirements of 250-350 mm pipe diameter in the natural gas and power industries, and studied its curve trafficability [15], as shown in Figure 8. The whole robot is crawler type, and the diameter changing mechanism adopts an adaptive diameter changing mechanism composed of lead screw nut and spring. The researchers have established a matrix model of the robot's bending, and carried out simulation and field experiments on the passing ability of the curve. The research results show that the speed coordination model can reduce the motor torque and energy consumption when passing the curve.

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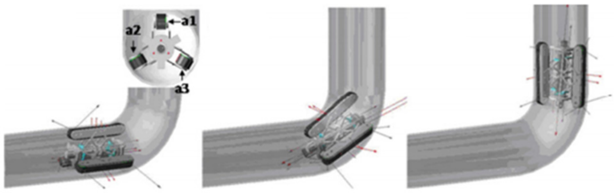

Figure 8. Natural gas pipeline inspection robot

In 2013, Professor Liu Qingyou from Southwest Petroleum University carried out research on the spiral pipe robot and proposed a novel design scheme for driving in the pipe [16]. Its design adopts modular design, and the conical spring link is used between the modules. The whole machine has compact structure and flexible movement. In 2014, the team proposed an active spiral pipe robot [17,18] to solve the problem of small drag force and low operation efficiency of the spiral pipe robot. As shown in Figure 9, the biggest feature of the robot is the combination of the wheeled pipe robot and the passive spiral pipe robot. The spiral wheel with a certain angle can realize active rotation through the reducer and has a pipe diameter adaptive structure, The robot spiral gear train moves in the way of plowing in the pipeline, so its traction force is much greater than that of the passive spiral pipeline robot of the same size. The experimental data shows that the traction force of the active spiral pipeline robot with the designed pipe diameter adaptation range of 75mm-100mm is 500N. However, the robot's screw driver and motor support are integrated. The overall size of the robot is very long, and it can only run in long straight pipes, not suitable for bending. During 2014-2017, Ren Tao and others from Southwest Petroleum University conducted extensive research on the motion behavior and mechanical behavior of the spiral pipeline robot, established the bending model of the spiral pipeline robot, proposed the bending theory of variable spiral angle and its implementation method, and carried out the preliminary research on the spiral pipeline robot for spiral measurement.

Figure 9. Active spiral pipeline robot

3. Research Difficulties of Pipeline Robot

From the above research status of pipeline robots at home and abroad, it can be seen that both at home and abroad, relevant scholars have done a lot of research work on pipeline robots and made corresponding achievements, making outstanding contributions to the development and practical engineering applications of pipeline robots. However, we should also see that the pipeline robot is still in the stage of improvement and upgrading, and has not reached the stage of maturity and application in the market. The main reasons are:

(1) Energy supply. There are two energy supply modes for pipeline robots: passive and cabled. Passive means that the robot carries batteries to supply all the actions of the robot in the pipeline. This method will first increase the weight of the robot, and then reduce the ability of

the robot to carry other equipment. Cabled type is commonly used by traditional in-pipe robots as a way of energy supply, but when the towed friction robot is used for long-distance transportation or uneven pipelines, the pipeline robot obviously has problems in walking with cables [19]. Therefore, the energy problem restricts the robot's long-distance driving and large towing power, and a portable long-distance energy supply mode is urgently needed.

(2) Communication problems. The pipeline robot acts on the buried metal pipelines of oil and natural gas. The signal acceptance ability is limited. The metal will shield part of the signal. The real-time transmission of robot information is difficult, which will affect the control accuracy and detection accuracy of the robot.

(3) Reliability issues. Obstacles such as impurity deposition and depression in the pipeline exist in the long-term use of the pipeline, which will seriously affect the motion stability of the pipeline robot. How to improve the obstacle surmounting performance and operation stability of the robot is crucial.

(4) In-tube flexibility. The transportation pipeline has the characteristics of long distance and complexity (curve, T-branch, variable-diameter pipeline, vertical pipeline). The pipeline robot should be driven, detected and controlled at the same time. The flexible operation in the pipeline should also be considered to ensure good trafficability in special places. This requires the precise and optimized design of the robot's mechanical structure.

(5) Integration of detection and repair. There are still limitations in the research and use of pipeline robots, that is, the integration of motion, detection and repair in the project is not yet perfect, and the self-perfection and self-repair functions of pipeline robot control system also need to be strengthened and developed [19].

4. Summary

In this paper, the current research situation of robot is systematically described by investigating the structure and working environment of existing pipeline robots. At the same time, on the basis of the current research situation, the development dilemma of the current pipeline robot is summarized, which will contribute reference value for the future pipeline robot research.

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