PNEUMOELECTRIC HYBRID: NEW BASELINE SURVEY METHOD

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Abstract:

Self-propelled detectors adopt electric drive. Driven by electricity, its gradeability is limited by the adhesion of the drive wheels and the transient discharge ability of high-energy disposable lithium batteries. At present, in terms of its gradeability and downhill ability, the slope angle is not more than 45 degrees, with a slope length of not more than 50 meters. A pneumatic drive would be needed as a supplement when there is an insufficient electrical drive. The case described in this paper uses blank pipe airflow to form a driving pressure difference to supplement the electrical drive in the case of having no back pressure on the pipe and when the detector discharges.

Adding a leather cup on the detector with some lift-off space to the pipe, namely, there is no contact between the cup and the pipe wall, forming a 5% discharge flow, with no frictional drag. The spreading of the cup will form a thrust force on the detector to make it run smoothly, which uses mass flow equivalent air volume air compressor to generate pneumatic thrust force.

Electric drive will supplement pneumatic drive when passing bends and pipe sections with increasing wall thickness and unbalanced resistance, while pneumatic drive will supplement electric drive when climbing. Electric drive and pneumatic drive help maintain the balanced running resistance of the detector, so as to achieve smooth running. The above-mentioned dynamic balancing process has been verified on trial. To date, the Φ325、Φ508、Φ711、Φ813、Φ914、Φ1067、Φ1219 pneumatic-electric hybrid drive self-propelled detectors have been trialed in field applications.

Keywords: Baseline inspection; Pneumoelectric hybrid; Pipeline in-line inspection; Self-propelled detectors

1. Introduction

As the most conventional and effective way to detect pipe wall deformation, defects, cracks, and other information, pipeline in-line inspection technology has been widely used in the safety hazard checking of oil and gas pipelines[1]. For the in-line inspection of pipelines in service, the general method is to use a pipeline transmission medium to form a pressure difference between the front and back of the detector in the pipe to drive the detector running in the pipe. Such pneumatic drive detectors have been used for many years. However, the pneumatic drive detector runs unsteadily under new pipelines and low pressure and low flow condition, and usually, it can not pass bends and areas with increasing abnormal friction. In most cases, the rear end of the detector needs to build the pressure to generate sufficient force to solve the blockage. There is a huge difference between the driving forces of passing straight pipes and passing bends, and the surplus driving force can not be released instantly when the detector enters a straight pipe from a bend, causing a sudden decrease in the resistance in the straight pipe, which makes the detector generate a tremendous amount of acceleration, causing velocity drift, greatly affecting the detection effect[2-4].

In recent years, Yang, etc. have developed self-propelled detectors. With an autonomous power system, the detector can complete in-line inspection work in the new pipe without a pipeline transmission medium, and it has good passing performance at bends. However, the detector needs to do extra work to overcome the weight component when climbing the uphill pipe section. If the slope angle is too large or there is increasing abnormal friction in the pipe, the self-propelled detector can not provide enough driving force to run smoothly as its gradeability is limited by the adhesion of the drive wheels and the transient discharge ability of high-energy disposable lithium batteries, which influences the inspection. Therefore, how to make the detector run stably and guarantee the detection effect becomes an urgent problem to be solved in the new pipeline inspection operation.

This paper introduces a detection robot based on the combination of a pneumatic drive and a self-propelled drive. It introduces the working principles of self-propelled drive and pneumatic drive. The characteristics of the two detection methods are analyzed respectively, and the technical route of the pneumoelectric hybrid drive is introduced. Through actual cases, the feasibility and reliability of the design scheme are verified and analyzed. This method breaks through the traditional scheme of baseline inspection, provides a new operation idea for baseline and future low-pressure and low-flow gas transmission pipelines, and effectively safeguards the safe operation of new pipelines.

2. Pneumoelectric Hybrid Drive Detector

2.1 Pneumatic drive robots

At present, pneumatic drive pipeline robots are widely used in the field of oil and gas pipeline in-line inspection engineering. They are self-driven by the pressure difference of the air between the two ends, which solves the problem of energy supply well, and is especially suitable for the detection of long-distance in-service oil and gas pipelines. However, such pipeline robots generally cannot change the running speed autonomously, and in the process of operation, they sometimes move slowly, sometimes fast; they sometimes run while sometimes stop. Besides, at bends and areas with thinning pipe walls, the dynamic leather cup is deformed and the pressure stress is increased, so the overall resistance of the equipment is greater than that of the conventional pipe sections. Therefore, the detector can not pass successfully without sufficient driving force under the new pipeline and low pressure and low flow condition. In most cases, the rear end of the detector needs to build the pressure to generate sufficient force to solve the blockage. While there is a huge difference between the driving forces of passing straight pipes and passing bends and the surplus driving force can not be released instantly when the detector enters a straight pipe from a bend, which causes a sudden decrease in the resistance in the straight pipe and makes the detector generate a tremendous amount of acceleration, forcing the detector to run at high speed[6]. The speed fluctuation will not only cause impact damage to the detector, but also seriously affect the accuracy of the detection data due to the high speed, and even invalid detection data collection. To sum up, the performance of pneumatic drive detectors in new pipelines is not ideal.

2.2 Pipeline self-propelled robot

The pipeline self-propelled detector has a total of 22 driving wheels. Each driving wheel is powered by a motor alone, and 22 motors are driven in parallel, with two odometer wheels to record the travel information, and one tachometer wheel to monitor the speed of the equipment in real-time during the detection process. In addition, the self-propelled detector also includes supporting springs, driving arms, and wheel legs to group into an organic unit with driving force, forming the main structure of the detector. Because of the support spring, the drive wheel can always keep a good fit to the pipe wall, and the detector can keep the ability to pass when the pipe diameter changes. Due to the fixed radius of the dynamic leather cup, the pneumatic drive detector will produce great resistance, causing a blockage when the pipe wall is depressed or the pipe diameter is changed. The self-propelled detector broke through the problem of the insufficient driving force of the pneumatic drive detector in the baseline inspection and can solve the problem of small changes in pipe diameter and insufficient driving force. They have been proven feasible in many engineering applications and completed many tasks of new baseline inspection.

However, three problems are found in the practical application of self-propelled detectors:

(1) Limited by the transient discharge ability of high energy disposable lithium batteries, the driving force provided by the driving wheels is limited under the limited condition such as a 90-degree vertical slope section;

(2) When the pipe wall surface is damp, the friction coefficient between the electric driving wheels and the pipe wall surface will be reduced, and the adhesion of the driving wheels will be affected, which will then affect the driving force of the whole detector;

(3) Due to the limitations of battery energy density, volume, and weight, there is no guarantee that the range of the detector can achieve full coverage of the pipeline when conducting long-distance detection operations.

Therefore, how to achieve stable operation of the detector in pipelines under extreme conditions has become a pain point that restricts the development of baseline inspection technology.

2.3 Analysis of pneumoelectric hybrid dynamics

The pneumoelectric hybrid drive robot, based on self-propelled robots, is equipped with an additional power cup, in which there is a certain space between the cup and the pipe and the radius of the power cup is 10mm less than the inner diameter of the pipe. This structural design enables the formation of a pressure difference between the front and back of the detector to provide power for the detector and avoids blockage caused by a sudden increase of resistance when the detector meets thinning pipe wall, deformed cups, and increased pressure stress at bends. The structure of the Φ1219 pneumoelectric hybrid drive detection robot used in this paper is shown in Figure 1.

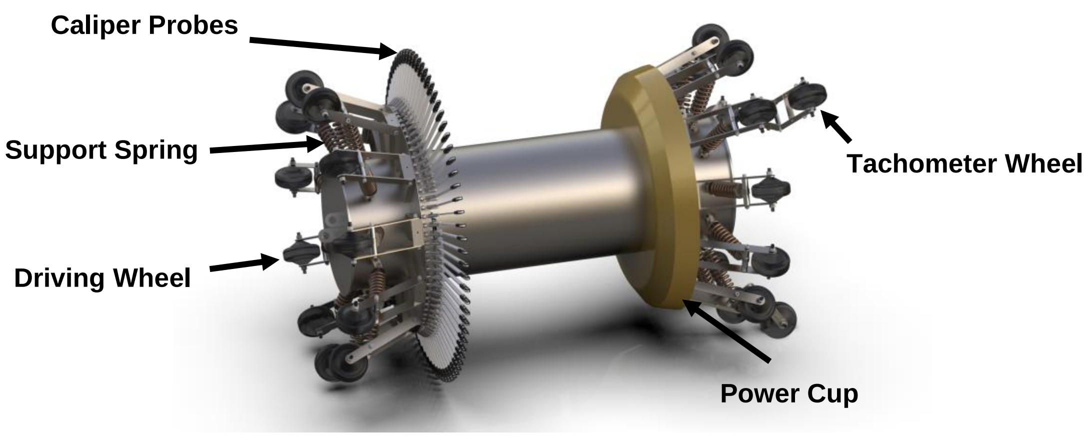

Figure 1 Pneumoelectric hybrid drive detector

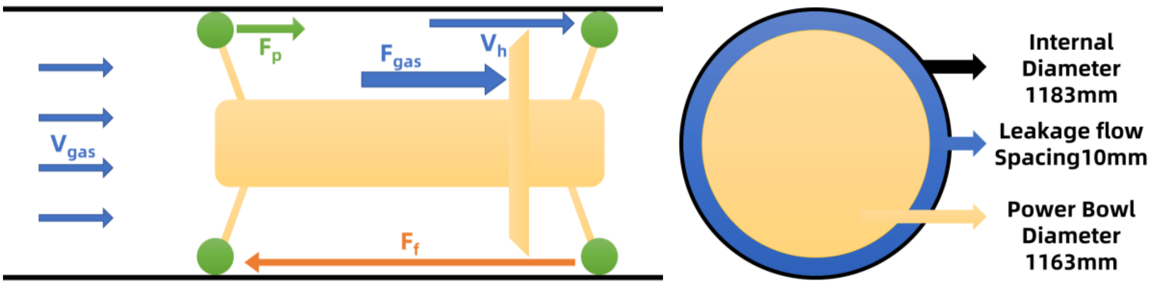

Figure 2 Dynamic analysis chart of pneumoelectric hybrid drive

Different from the pneumatic drive detector, the cup of the pneumatic drive detector has a magnitude of interference, and the pressure difference is established by isolating the air before and after it to provide the driving force for the detector, while the pneumatic theory of this pneumoelectric hybrid drive detector is the phenomenon of air discharge between the power cup and the pipe wall, causing a local pressure loss. Such pressure drop relation is related to the overall pressure drop resistance factor of the detector and the bypass flow rate[7-9]. The pressure difference between the front and back, ΔP, established by the gas discharge around the detector, is:

$$\Delta P = \frac{K_P \rho V_h{}^2}{2} \#(1)$$

$$V_h{}^2 = \left(\frac{A}{A_h}\right)^2 \Delta V^2 \#(2)$$

$$\Delta V = |V_{gas} - V_{pig}| \#(3)$$

The pressure drop coefficient gas discharge is K_p=1.43; ρ is the air density,1.205kg/m^3; V_h is the gas discharge velocity, A_h=0.0368m^2 the discharge area, the pipeline cross-sectional area A=1.0986m^2, V_{gas} the flow rate of gas in the pipeline, V_{pig} the running speed of the detector and ΔV the relative speed of the detector and the flowing gas. The driving force provided by the gas pressure difference for the detector is:

$$\mathrm{F_{gas}} = \Delta P(A - A_h)\#(4)$$

The driving force required by the horizontal section of the pipeline is 800N measured by the pull-through test. To keep the running speed of the detector at 1.5m/s, formula (1-4) is used to obtain that when the inlet flow rate reaches 2.5m/s, the gas can establish a pressure difference of 760Pa before and after the detector, providing the detector with a driving force of F_{gas}=800N, which makes the detector run smoothly in the horizontal pipe section.

Under extreme conditions such as vertical uphill pipe section, the total required driving force should be:

$$\mathrm{F_{up}} = \mathrm{mg}\sin\theta + \mathrm{F_f}\#(5)$$

Where m=640kg, θ is 90°, friction resistance F_f=800N, and F_{up}=7072N. When the relative speed between gas and the detector ΔV =2.5m/s, the maximum driving force F_{gas} will reach 5000N; the torque of the self-propelled driving wheel is 17.7nm, the radius of the driving wheel is 0.078m, and the total driving force of the driving wheel is F_p=5000N. When driven by the pneumoelectric hybrid drive, the detector can pass smoothly under extreme conditions.

As shown in Figure 3, the overall working mechanism of this pneumoelectric hybrid detector is:
(1) For the horizontal pipe section with uniform resistance, the conventional resistance is measured by a pull-through test, and the inlet gas flow rate is determined by hydrodynamics calculation. The pressure difference of air can provide the driving force for the detector, and the self-propelled motor does not intervene in the work;
(2) Uphill pipe sections/pipe sections with abnormally increasing resistance can be identified by the attitude sensor and velocity-measuring system. At this time, the pneumatic force cannot meet the demand of driving force for the detector to run stably. Then the control system supplies power to the self-propelled driving motor, and the self-propelled driving wheels start to work to provide power compensation.
(3) When the attitude sensor/tachometer wheel senses that the robot is in the downhill/overspeed state, the control system will cut off the power to the driving motor and connect the major loop to the brake resistance to control the device within the established speed range.
(4) When the detector stops at a bend, tees, and other special parts, the self-propelled driving wheels will work to ensure that the detector passes through the bend and other parts.

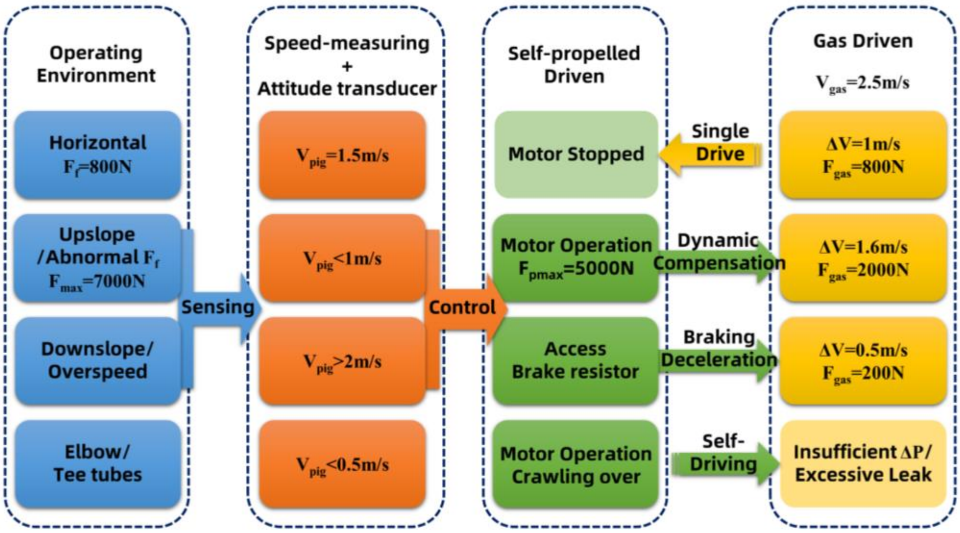

Figure 3 Working mechanism of pneumoelectric hybrid drive

3. Field Application Cases

The pneumoelectric hybrid drive detector has been put into use in a new pipe somewhere. Geometric deformation probes were carried out to detect the deformation of the pipeline, which has a total length of 67km and a diameter of 1219mm, with two long uphill sections (section 1.2 in Figure 5), including a steep uphill section. According to the above scheme design, six air compressors with a flow rate of 30m^3/min are used to work at the pipeline entrance, so that the gas inlet flow rate of the pipeline is maintained at about 2.5m/s, and the pipe outlet is atmospheric pressure. The inlet pressure of the pipeline is measured to be 1.6KPa under operating conditions.

Figure 4 Baseline inspection site

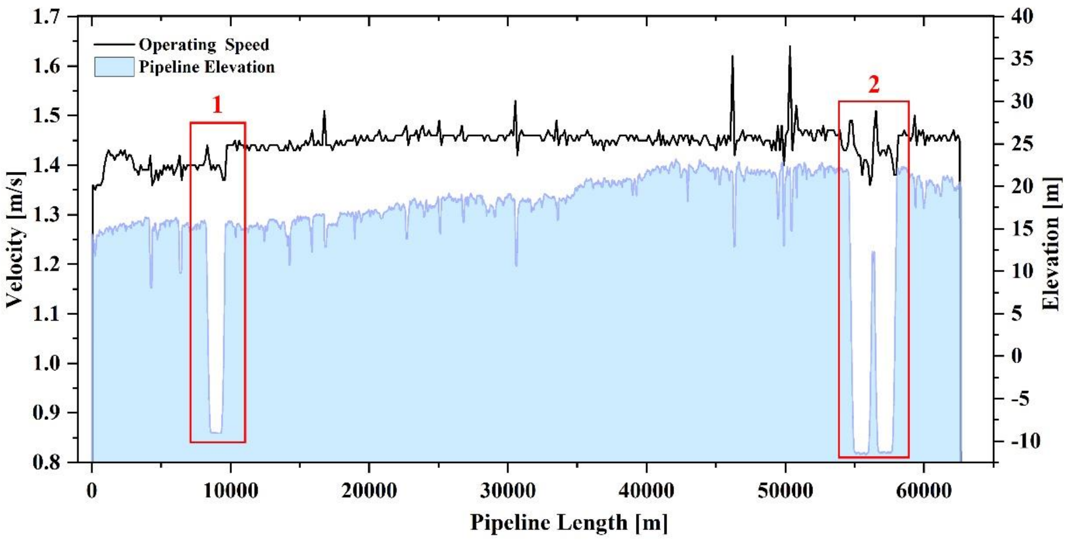

Figure 5 Pipeline elevation and detector running speed

The running speed of the detector and the elevation along the pipeline are shown in the figure. After completing the field operation, the data on the detector's running speed is obtained. The detector runs smoothly and the speed is stable at about 1.5m/s. Combined with the elevation along the pipeline, the stable running expected by this method is achieved. At 95464m (part 1 in Figure 5), the running speed of the detector at the uphill section of a steep slope showed a slight downward trend at the beginning; however, under the dynamic compensation of self-propelled drive in this method, the running speed of the detector is stabilized at about 1.45m/s again; at 56795m (part 2 as shown in Figure 5), under the condition of two consecutive steep slopes, the detector in the operation process showed relatively large speed fluctuations, but the overall fluctuation of the running speed is not more than 0.1 m/s, besides, this section had a vertical uphill section, and the pneumoelectric hybrid drive detector showed its powerful gradeability, without stagnation and blockage. And its speed has been stable at 1.35m/s above, achieving the expected goal of the design scheme. According to the operating results of the detector, the pneumoelectric hybrid drive detector shows strong stability in the strict engineering environment and can realize stable operation in the steep slope pipe section, ensuring the stability of the detection effect. Through this field test, the reliability of the detector under a long-distance complex pipeline is verified, and the feasibility of the design method in baseline inspection is verified.

4. Conclusion

Combining the pneumatic drive and electric drive energy supply systems helps solve two problems for the new baseline inspection operation scheme introduced in this paper. First, the detector will not be limited by insufficient power drive when climbing, second, the pneumatic drive detector will not be prone to get stuck at the bend when passing low-pressure and low-flow pipelines. In the field application of Φ1219 baseline pipeline, the running speed of the detector along the line shows high stability, which verifies the feasibility of this pneumoelectric hybrid drive method to ensure stable operation of baseline inspection. This method can greatly reduce the risk of blockage during baseline inspection and effectively ensure the stability of the detection effect. At the same time, this method will provide a new way to solve the problem of low-pressure and low flow gas pipeline in-line inspection project.

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