Design of Intelligent Drifting Ball for Pressure Pipeline Inner Inspection Using Ultrasonic Technique

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Abstract. There are often corrosion and scaling on the inner wall of industrial pressure pipes. The spherical detector for pipeline internal inspection was proposed in the paper. The detector could be rolled with the fluid movement and collected a variety of information along the way by equipped with sensors such as ultrasonic probes. The presence and precise positioning of defects could be determined. The mechanical structure is the carrier of the spherical detector. One of the characteristics of spherical detector is that a number of probes are arranged on the spherical surface. In order to realize the above structure design, an algorithm for generating probe position was studied, and the probe is placed on the spherical shell by using this algorithm. The experimental results show that the mechanical structure has stable motion attitude. And the detector has good scaling performance, pressure resistance and internal structure layout. The research results of paper lay a foundation for the precise positioning of defects, and have important significance for ensuring the safe operation of pressure pipelines.

1. Introduction
Corrosion is the most common defect in the use of pipelines, especially for buried pipeline [1–2]. With the prolongation of using, there will be corrosion pits and wall thinning in buried pipeline, since the corrosion and erosion by soil or medium [3]. Corrosion will reduce the bearing section of pipeline, and even, cause pipeline rupture and medium leakage when serious [4]. While most of the medium transported by pressure pipelines are explosive, toxic or destructive to the environment, it may even lead to explosion accidents when pipeline has serious leakage, causing casualties, environmental pollution and huge economic losses, thus affecting social stability [5–6]. Thus it is of great significance to detect and record the integrity of pipelines by various detection techniques, in order to detect pipeline defects in advance, eliminate potential accident and prevent accidents.

Based on the material and structure characteristics of pressure pipeline, an intelligent drifting ball for inner inspection of pressure pipeline was proposed in the paper. The diameter of the detection ball is about 75\% of the inner diameter of pipeline, and the specific gravity is basically the same as that of the water. The detection ball can move smoothly with the water in the pipeline without pipe stuck. The
automatic detection of pressure pipeline is realized by the ultrasonic probes arranged on the sphere of detection ball. Finally the detection and evaluation of the corrosion and other defects of pipeline were finished, so as to ensure the safe operation of pressure pipeline.

2. Design for Spherical Detector
In order to be applicable to pipeline detection with a maximum pressure of 2-10Mpa, the first thing is to ensure the sealing performance of the spherical detector to meet the withstand pressure requirement. The appropriate design flow of the detector was established, and the structure design was carried out in a reasonable order. The design of the spherical detector in diameter, sealing performance and internal structure were discussed. The experiment was carried out on the designed structure to ensure the effect of field detection.

One of the characteristics of spherical detector is that a number of probes are arranged on the spherical surface. During the operation of the detector, there is always a group of probe whose sound beams can be vertical or basically perpendicular to the inner wall along the circumferential direction of the pipeline. So that the probe can receive the ultrasonic signal to detect the corrosion of the pipe wall. In order to realize the above structure design, an algorithm for generating probe position was studied, and the probe is placed on the spherical shell by using this algorithm.

The paper combines the law of ultrasonic echo intensity varying with angle and related ultrasonic detection theory to place probes on the sphere. The probe adopts a circular wafer, which is arranged on three mutually perpendicular planes along the sphere, i.e., plane X, Y, Z, shown in Figure 1. A probe is arranged every 15 degrees on each plane. The probe on the plane Y is responsible for detecting the inner wall of the horizontal pipeline. The probe on the plane X is responsible for detecting the inner wall of the vertical pipeline. And the probe on the plane Z is responsible for detecting the inner wall of the elbow when it passes through.

3. Solution for Pipe Stuck of Detector
The intelligent drifting ball uses liquid hydrodynamic force to move in the pressure pipeline. And the most common and difficult problem is pipe stuck during the internal detection process. The diameter of ball is designed to be smaller than that of pipe, in order to avoid stuck accident. On the other hand, the equivalent density of the whole detector is determined as the density of liquid fluid in the design for obtaining a stable detection quality. Therefore, the internal detector, driven by the fluid, will move forward smoothly in the liquid, as shown in Figure 2, and its speed can be indirectly influenced and controlled by the flow rate.
Figure 2. The internal detector uses liquid hydrodynamic force to move in pipeline.

In some practical cases, there may be large obstacles in the pipeline, so it is necessary to adjust the design of the intelligent drifting ball according to the situation. Sometimes the diameter can even be designed as 1/2 of the inner diameter of pipe according to the actual situation, and the corresponding structure needs to be more compact. Therefore, a suitable design method of sphere specifications should be proposed considering the possible obstruction, structural change and driving force in liquid medium.

4. System Performance of Spherical Detector

The design core of intelligent drifting ball lies in the reasonable assembly of spherical shell, ultrasonic probe, ultrasonic card, accelerometer, magnetometer, battery, embedded computing platform, memory and other components in a narrow spherical space, and forming a set of functions, such as receiving and receiving control, synchronization and processing of ultrasonic signals. The whole intelligent sphere device includes spherical polyurethane shell 1, ultrasonic probe 2, multi-channel ultrasonic card 3, guide plate 4, accelerometer 5, magnetometer 6, high-efficiency battery 7, embedded system 8, U disk storage 9 and screw plug 10, etc. Its structure schematic diagram is shown in Figure 3.

Figure 3. The structure schematic diagram of the intelligent drifting ball.

A large number of ultrasonic probes are distributed on three planes of polyurethane spherical shell. During the move of the detector, there is always a group of probe whose sound beams can be vertical or basically perpendicular to the inner wall along the circumferential direction of the pipeline. So that the probe can receive the ultrasonic signal to detect the corrosion of the pipe wall. The outer layer of the intelligent ball is a guild plate. Driven by the liquid pressure difference in the tube, the whole device is moves forward.

Each ultrasonic probe is connected to the multi-channel ultrasonic card through a cable. Due to the limited space of the internal detector, the ultrasonic card is required to have features of high integration, low power consumption, super-large storage capacity, and fast signal processing.
detection. All thickness measurement functions such as transmitting control, receiving control, high-speed A/D acquisition and digital processing of ultrasound signal can be accomplished by the ultrasonic signal acquisition card alone. The working principle diagram of ultrasonic detection and signal processing is shown in Figure 4.

![Ultrasonic detection and signal processing diagram](image)

**Figure 4.** The working principle diagram of ultrasonic detection and signal processing.

Ultrasound cards with many channels are used to control the transmission and reception of the corresponding number of ultrasonic probes. The card adopts parallel detection, decentralized signal processing and decentralized data storage, which can improve the scalability, real-time performance, data storage and reliability of multi-channel. The ultrasonic signal of a large number of probes collected by the ultrasonic card and the position information obtained by the accelerometer 5 through data processing are simultaneously input into the embedded system 8. And ultrasound detection data and position data require strict synchronization, controlled by synchronization trigger time series average method. Data storage uses U-disk memory. At the end of detection, U-disk memory can be taken out, and thickness measurement data can be displayed by off-line analysis and processing. Before the implementation of detection, parameters of ultrasonic card are set according to pipeline specifications and materials, including opening channels, setting sampling delay time, sampling gain, sampling frequency, waveform type, baseline setting, sampling depth, etc., to obtain buffer address and realize the initialization of ultrasonic board card. After completing the online inspection task, the inspection data are taken out, and the stored data are processed by the off-line inspection data analysis system to complete the pipeline thickness measurement data processing and display.

5. Conclusion
According to the detected tests carried out on a pipeline test platform with various typical corrosion and artificial defects, the results shown that, the detection method proposed in this paper can detect the corrosion condition and defect distribution of pipelines. And the size and shape parameters of corrosion defects can be obtained according to the test results. Therefore the safety of pipeline can be evaluated on this basis to ensure the safe operation of the pipeline.

Meanwhile, the intelligent drifting ball can transform the fluid pressure into the robot power, providing a solution for the robot energy supply problem.

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