Study on On-line Monitoring of Valves leakage

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ABSTRACT

In the actual operation of the valve, leakage often occurs at the filling box, but lack of effective monitoring means. According to the actual demand, the leakage of valve packing is studied experimentally, the bubble detection scheme is designed, the single bubble volume calibration experiment is carried out, and the relationship between the leakage gas quantity and the bubble number is established. An on-line monitoring system for valve leakage is developed and designed. The system uses ultrasonic bubble sensor to detect bubble generation and obtain leakage information in real time.

1. Introduction

In modern industrial equipment, valves are widely used in complex variety and poor working environment as a general purpose machinery. Valve should have better sealing performance, strength performance, regulating performance, etc. However, the overall level of seal structure design technology is not high[1]. Valve leakage failures occur frequently, seriously threatening the safety of staff. At present, the valve leakage detection is still lack of effective detection means, the valve leakage detection depends on people's hearing, vision and other senses and experience to judge the valve leakage detection. At present, the main detection methods of valve leakage at home and abroad include manual inspection, ultrasonic detection and vibration analysis. This study aims at the leakage outside the valve, uses the bubble detection method to carry on the leakage monitoring.

2. Design of Monitoring Scheme

2.1 Cause Analysis of Valve Leakage

The leakage of valves can be divided into internal leakage and external leakage. Internal leakage refers to the leakage of gas or liquid in the flow direction of the pipeline, and external leakage refers to the leakage into the external environment of the pipeline. In most cases, the consequences of external leaks tend to be more serious than internal leaks. Leakage is common in the body, stem, stuffing box and body connection. A summary of the leakage out of the valve is summarized as follows:

Valve packing leakage and causes: there is a relative movement between the stem and the packing during the operation of the valve, which includes rotation and axial movement[2]. As the number of switches increases, the number of relative movements increases, as well as the effects of temperature, pressure and the characteristics of fluid media, the valve packing is the most prone to leakage. It is caused by the gradual weakening of contact pressure of fillers, the aging of fillers and the loss of...
elasticity. The pressure medium will leak out along the contact gap between the packing and the stem and blow away part of the packing and wash the stem out of the groove for a long time. The causes of leakage at packing are loosening of packing gland, untight packing, nonconformity of packing variety or quality, aging of packing or wear of valve stem.

Body leakage occur in any part except packing and flange sealing generally. The body is produced mainly by casting or forging. If there are defects in casting or forging, there are sand holes in the valve body, and they will lead to the leakage of the medium. Corrosion occurs mainly in the form of homogeneous corrosion. Causes of stem leakage: valve stem due to material selection and design problems will cause stem in a certain position is stuck, so that the valve can not close or close loosely, resulting in media leakage[3]. In use, there is relative movement between the stem and the packing, including rotation and axial movement. With the increase of opening times in use, the relative motion times also increase, in addition, there are the influence of high pressure, high temperature and strong permeability fluid medium, valve stuffing box is also the place where more leakage accidents occur. The main cause of packing leakage is interface leakage. The interface leakage between the valve stem and the packing is caused by the gradual weakening of the contact pressure of the packing, the aging of the packing itself, and the leakage of the pressure medium along the contact gap between the packing and the stem. The stem structure is shown in figure.1

![Figure 1. The structure of valve stem seal](image)

Cause of leakage in body connection: sealing at body connection is the seal between body and cover, usually is flange connection seal, thread connection seal when valve nominal diameter is smaller. The material type or size of the gasket does not meet the requirements, improper fastening of the connecting bolt, poor machining quality of the flange sealing surface and excessive additional load at the joint due to unreasonable pipe configuration can all cause leakage of the valve body connection.

By synthetically analyzing the reason of valve leakage, we can see that the leakage formed in the design, manufacture and transportation of valve can be controlled reliably through early effective inspection and detection[4]. The leakage caused by valve during installation and use is mainly caused by leakage caused by seal damage of flange or stem stuffing box in valve connection and internal leakage caused by failure of seat sealing surface. The leakage caused by seal damage of stem stuffing box is the most serious. According to statistics, 80% of valve leakage is due to damage to the sealing surface caused by.
2.2 Bubble Detection Scheme Flow

Bubble leak detection method is often used in the detection of valve leakage, that is, the valve with gas immersed in the liquid, the workers count the number of bubbles out of the valve in a certain period of time. The quality grade of a valve (such as qualified, first grade and top grade, etc.) is judged by comparing the leakage rate standard of a certain type of valve seal test. This method is simple and easy to use\textsuperscript{[5]}. It can detect a small leakage rate, but it requires a lot of labor and working hours, and it is inefficient. In this paper, the bubble detection method and ultrasonic detection method are combined, and the method is applied to valve leakage monitoring. The basic flow of the leakage monitoring scheme studied in this paper is shown in figure 2.

![Diagram of bubble detection scheme](image)

**Figure 2.** The process of detection devices through bubble detection

The principle of the scheme is that the leakage gas is collected, the leakage gas is passed into the metal tube filled with ionic liquid, the bubble produced in the metal tube is detected by ultrasonic probe, the bubble signal is transmitted to the control circuit, and the leakage is calculated by the level signal received per unit time. The schematic diagram is shown in figure 3.

2.3 Monitoring scheme analysis

- There is no limit to the application of valves, no need to consider the pressure level of the valve, for ultra-low pressure or ultra-high pressure conditions can be tested;
- The scheme uses ionic liquids, which have the characteristics of difficult volatility and do not need to add liquids regularly;
- The scheme uses electrical signal to detect leakage quantity, which has high sensitivity and reliable monitoring results.
- This scheme is limited to the condition that the working medium is gas.
3. Experimental verification of monitoring scheme

3.1 Ultrasonic Bubble Sensor

The principle of ultrasonic bubble sensor detection is shown in Figure 4. The ultrasonic transducer chip at the transmitter and the receiver is encapsulated in a cylindrical shell with an inner void\(^6\). After the ultrasonic wave is emitted from the transmitter, a small portion of the chip is diffuse reflected by the sensor shell, most of which passes through the shell and the air gap. Once again through the pipe wall into the flow of liquid. During the transmission process, a small part of energy is lost in the air gap, the other part is attenuated by the structure of the pipe wall material, and most of the energy is transmitted to the ultrasonic transducer at the receiving end in the flowing liquid. If there are no bubbles in the liquid, the density of the liquid is relatively stable, and the signal received by the receiver has almost no big distortion. If there are bubbles of different sizes in the flowing liquid, the density of the liquid will decrease, the energy received at the receiving end will attenuate, the signal waveform will be distorted, and the amplitude will become smaller\(^7\). The attenuation degree and time are related to the bubble size, shape and bubble number. The output signal of the sensor is a voltage signal, the sensor will output the low level signal when the bubble passes through the detection area of the ultrasonic probe, otherwise it will always output the high level signal.
3.2 Valve Leakage Calibration

In order to determine the relationship between the leakage rate and the number of bubbles, the calibration experiment of the leakage rate has been carried out in this study. A certain amount of gas is passed into a metal tube containing ionic liquid, the number of bubbles produced in ionic liquid is detected by ultrasonic bubble sensor, and the relationship between the amount of gas entering and the number of bubbles is established[8]. Based on the results, the relationship between the leakage rate and the number of bubbles can be calibrated. The instrument used in the leak calibration experiment is shown in Table 1.

<table>
<thead>
<tr>
<th>Reagent&amp; instrument</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>injection pump</td>
<td>LSP01-1A</td>
</tr>
<tr>
<td>deionized water</td>
<td>H2O</td>
</tr>
<tr>
<td>absolute ethyl alcohol</td>
<td>C2H6O</td>
</tr>
<tr>
<td>ionic liquid</td>
<td>C8H15N2BF4</td>
</tr>
<tr>
<td>Bubble detection sensor</td>
<td>MLU02-209</td>
</tr>
<tr>
<td>NI acquisition card</td>
<td>NI cDAQ-9174/NI 9205</td>
</tr>
<tr>
<td>injector</td>
<td>10ml</td>
</tr>
</tbody>
</table>

The experimental process of single bubble volume calibration is as follows: the injection pump is used to inject the gas at the entrance of the gas, the volume quantity of the gas (Q) injected into the injection pump and the rate of gas injection are adjusted, and a bubble detection sensor is installed on the outer surface of the metal tube containing ionic liquid. Then LABVIEW is used as the software development platform and the hardware is the muti-function data acquisition card of NI Company[9]. The number of bubbles (n) produced by different volume quantities (Q) is determined by signal processing, and the volume size of a single bubble (q/ml) can be determined according to the bubble volume relationship, which is shown in formula (1).

\[ q = \frac{Q}{n} \]  

(1)

In this study, the LABVIEW software is used to collect the output voltage signal of the sensor by using NI acquisition card[10], and the final bubble number is determined. The block diagram of the LABVIEW program used in the experiment acquisition process is shown in figure 5.

![Data collection program based on LABVIEW](image)
3.3 Effect of leakage rate on bubble size

The signal collected by NI voltage acquisition card is shown in figure 6.

![Figure 6](image)

**Figure 6.** The output signals of bubble-detector

The bubble aperture in the experiment is 0.5mm and 0.9mm respectively. The experimental results are shown in figure 7 ~ figure 14 below.

![Figure 7](image)

**Figure 7.** The rate of leakage is 0.5mL/min

![Figure 8](image)

**Figure 8.** The rate of leakage is 1.0mL/min

![Figure 9](image)

**Figure 9.** The rate of leakage is 1.5mL/min

![Figure 10](image)

**Figure 10.** The rate of leakage is 2.0mL/min
The relationship between the volume of gas leakage and the number of bubbles is processed to obtain the volume of a single bubble. The relationship between the volume of a single gas and the leakage rate is shown in figure 15. below. From the above results, the following conclusions can be drawn\(^{[11]}\):

- The volume size of a single bubble is independent of the volume size and leakage rate of the leakage gas when the diameter of the bubble mouth is constant.

The experimental results show that the bubble aperture is 0.9 mm, the single bubble volume is 0.02 ml, the single bubble diameter is 3.3677 mm, the bubble aperture is 0.5 mm, the bubble volume is 0.015 ml, and the bubble diameter is 3.05 mm.
4. Control Circuit Design

With the development of modern industry, the requirement of reliability, high speed, real time and remote controllability of data acquisition system for industrial production and product detection is becoming higher and higher\cite{12}. At present, in the field of industrial control, the common data acquisition system uses DSP or FPGA as the main control chip of the data acquisition card to realize the data receiving and overall control of the system\cite{13}, but it is difficult to ensure the real-time and reliability of the data acquisition in such a system. At the same time, the common data acquisition system, in the data transmission between the lower computer (data acquisition device) and the upper computer (PC), mostly adopts the transmission mode based on USB bus or PCI bus, so it is difficult to realize the remote transmission of the system\cite{14}. Moreover, the amount of data transmission in unit time is small, so it is difficult to meet the demand of industrial detection. The recently proposed data transmission method based on optical fiber communication, because every optical fiber needs an optical terminal to convert optical signals into electrical signals, this method will greatly increase the transmission cost and the complexity of the system, so it is not practical at present.

At present, embedded technology has been used in many fields of detection. In the information age, the digital age makes the embedded products have a great opportunity to develop, showing a bright future for the embedded market\cite{15}. The embedded chip not only processes tens of megabytes of instructions per second, but also has the function of pipelining, which speeds up the processing speed greatly. Developers can use embedded operating system functions to develop their own applications, thus shortening the product development cycle. Therefore, it is necessary to use embedded chip in industrial control and monitoring system. In this paper, The development process of embedded system design is shown in figure 16 below.

![Diagram](image)

**Figure 16.** The process of the embedded system
In this paper, the minimum system circuit, voltage stabilizer circuit, level conversion circuit and acoustic-optic alarm circuit are designed based on ATmega48 micro controller.

The ATmega series is a new type of high-grade AVR single-chip computer based on the AVR RISC structure of ATMEL Company\[16\]. In the AVR family, ATmega48 is a special single-chip microcomputer, ATmega48 retains the core of ATmega series. It integrates large capacity memory and rich hardware interface circuit inside the chip, and it cuts the peripheral pin, memory and peripheral expansion of ATmega series chip, at the same time, it is specially designed for power consumption. ATmega48 has the characteristics of low cost, low power consumption and powerful function\[17\]. It is widely used in electrical appliances, instruments, power supply and other industries.

As a powerful MCU, ATmega48 provides a flexible and low cost solution for many embedded control applications. Figure 17. shows the pin distribution of ATmega48 in this system\[18\]. PC6 / RESET is the reset pin. Connect the external reset circuit PD0 and PD1 as the sensor detection circuit signal input port VCC and GND as the power supply connection port PB6 as the reverse oscillation amplifier and internal clock operation circuit input PB7 as the output of the reverse oscillation amplifier. PD5 and PD6 is the test point to connect the external LED flicker alarm circuit PB2 to the external buzzer alarm circuit PB3 / PB4 / PB5. For online debugging and downloading programs.

Figure 17. The pin assignment of ATmega48

In order to upload the leaked information in real time, we use USR-GM3 module to upload the data to the server. USR-GM3 is a highly integrated UART to GSM/GPRS communication module, which can be used to realize the transparent transmission of two-way data from serial port to network conveniently\[19\]. This module is different from the commonly used GPRS module in the market, it needs to understand the complicated instruction and protocol, this module is a kind of minimum type GPRS DTU. The module can use the card, followed by a built-in sim card version of USR-GM3S, which can be powered without the need for a built-in sim card. The module is shown in the figure 18.
We have designed the schematic diagram and drawn out the PCB diagram, and finished the component welding after machining. The final control circuit is shown in figure 19.

The real-time monitoring data of the valve leakage detection scheme in this study will be uploaded to the cloud server. Based on this, a set of software developed by VB.Net is designed to receive the real-time information of leakage, and the software can set up warning lines. When the output value of the leak detection sensor exceeds the warning line, the software will prompt the alarm. We test the monitoring system with injection pump simulated valve leakage. The test results are shown in figure 19. and figure 20.
5. Conclusions

This paper provides a complete on-line monitoring scheme for valve leakage. Firstly, the feasibility and accuracy of bubble detection method are verified experimentally, and the bubble volume is measured when the bubble aperture is 0.5mm and 0.9mm, respectively. The results show that under the condition of bubble aperture confirmation, the volume of single bubble is almost fixed, and the bubble detection method is feasible for valve leakage monitoring. Secondly, the research uses ultrasonic bubble sensor to detect the bubble signal, processes the signal through embedded circuit to obtain the leaked information, uploads the server, and displays it in real time. The monitoring results are more sensitive and accurate. At the same time, the alarm value of leakage quantity can be set. If the leakage amount exceeds the alarm value, the acoustic-optic alarm will be activated, which will help the enterprise to find the leakage failure of the valve quickly and reduce the loss. Finally, the problem of valve leakage in other working media can not be solved only when the working medium is gas.

References and Footnotes


