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Study on Detection Method of Acoustic Emission Leakage in Ball Valve of Natural Gas Pipeline

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Abstract

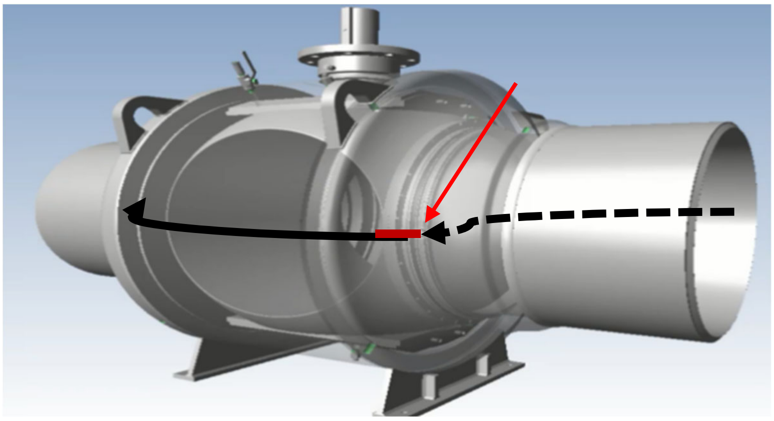
As a key control component in the fluid transportation system of petroleum, chemical industry and long distance transportation pipeline, the leakage fault in the ball valve seriously disturbs and affects the normal oil and gas production.In this paper, acoustic emission technology is used to detect the leakage in ball valves. Based on the acoustic emission theory, the mechanism of the leakage in ball valves is explored. Acoustic emission detection experiments to extract acoustic emission signal, through CEEMDAN to extract the amplitude of signal denoising, signal to noise ratio is 8.61, with amplitude signal peak, the RMS (RMS), ASL (average signal level), pressure as the characteristic values of application of SVR (support vector regression machine) for ball valve leakage rate of inversion, the mean square error is 3.22, the correlation coefficient is 0.9842, the result shows that the SVR algorithm used for ball valve leak rate of inversion is feasible.

Keywords

Ball valve leakage; Acoustic emission; Finite element simulation; Signal denoising; Signal inversionr.

1. Introduction

Ball valve is a key control part in the fluid conveying system such as petroleum, chemical industry and long distance pipeline. In daily production and operation, ball valve leakage is a common problem. The internal leakage fault seriously disturbs and affects the normal production of oil and gas transmission, has great influence on the safety regulation and quality control of oil and gas pipelines, and has great safety hidden trouble, affecting the safe production operation of oil and gas transport and equipment maintenance and overhaul. The causes of ball valve leakage are various, mainly caused by three types: plastic deformation exists at the edge of the valve body. When the valve is closed, the deformation part interferes with the seat causing the switch not in place, which can lead to serious ball valve leakage. When the valve is switched, the hard particles are embedded into the sealing surface, causing damage to the sealing surface due to the relative movement with the seat, leading to moderate leakage in the ball valve; When the valve is closed, the hard particles are crushed and worn, which causes the valve coating to peel off and the valve body to scratch, causing the ball valve to leak slightly. Ball valve leakage in the form can be roughly divided into two categories, described as a small opening and lax seal. That is, when the ball valve is closed, there is a gap on the upstream side, and the fluid flows out from the downstream clearance on the other side through the flow passage; Loose sealing is described as fluid flowing into the upstream clearance, filling the flow passage and valve chamber and then flowing out of the ipsilar downstream clearance. See Figure 1.



A) Small opening b) lax seal
Fig 1. Leakage form in ball valve

The commonly used leak detection methods in ball valves include negative pressure wave detection, ultrasonic detection, vibration detection and so on. The negative pressure wave detection method is to determine the leakage position according to the time difference between the generated negative pressure wave and the sensors at both ends when the valve leaks. It has poor anti-interference ability and is not suitable for high temperature inflammable and explosive environment, so it is not suitable for the leakage detection in the valve of long transmission pipeline. Ultrasonic testing is to judge the defects of materials by the difference of reflected energy of ultrasonic in the medium and its defects. It can be used for the non-destructive detection of leakage inside the valve on the ground of the long transport pipeline with high safety and fast detection speed. However, it is difficult to detect the valve buried in the ground and not applicable to the complex valve structure. Vibration detection method is to detect the vibration signal to determine whether there is internal leakage. In this paper, acoustic emission detection method with good stability and high accuracy is adopted to detect the leakage inside the ball valve, and finite element analysis is used to simulate the flow field and sound field of the leakage inside the ball valve. Finally, acoustic emission detection experiment is carried out to process the acoustic signal and invert the leakage rate inside the valve.

2. Internal Leakage Mechanism of Ball Valve

2.1. Noise Leakage Source in the Ball Valve

When leakage occurs in the closed state of the ball valve, due to the interception effect will produce pressure drop in the leakage position, fluid turbulence, speed up the flow rate, impact on the valve body and pipe wall, causing stress wave, and then form noise. The noise source is usually composed of jet noise, blocking jet noise and eddy current noise []. The noise generated by leakage in the ball valve is mainly jet noise generated by high-speed fluid jetting from small leakage orifice to the downstream pipe of the valve, which can be described by axisymmetric jet model, as shown in Figure 2.

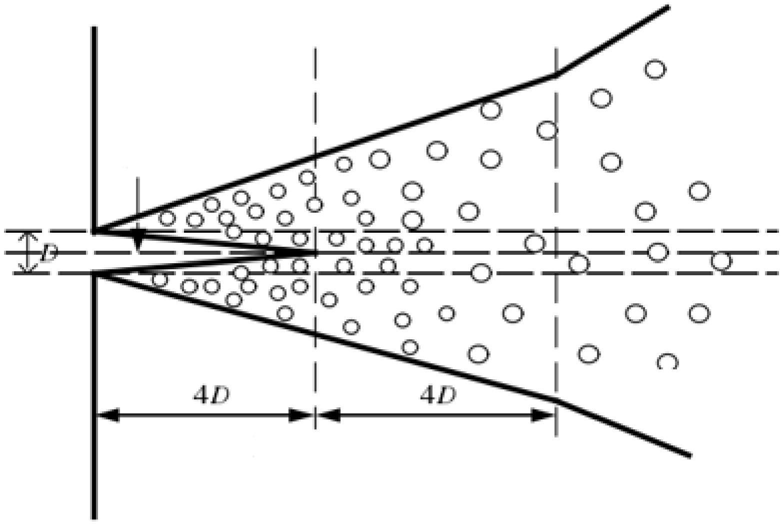


Fig 2. Leakage flow model in ball valve

When the fluid is ejected from the nozzle with diameter D, three zones will be formed during the jet flow process: mixing zone, transition zone and fully developed zone [].Core fluid jet, jet noise exists in a cone area, and its speed approximately equal leaking orifice, around the core area, the jet flow experience with the surrounding fluid leakage form the entrainment effect, resulting in a high frequency noise, and mixed areas transverse length of about 4 times the diameter of the orifice, more valves for this range of leakage flow noise.The noise intensity of the second region is smaller than that of the mixing region at the diameter of the downstream 4D~8D orifice. After the transition zone is the full development zone, the jet noise generated by it is small.

2.2. Theory of Acoustic Emission Leakage Detection in Ball Valve

Based on The Navier-Stokes (N-S) equation, Wright Hill established the equation to deal with the gas jet noise, namely the Wright Hill equation [33].

$$\frac{\partial^2 p}{\partial t^2} - c^2 \nabla^2 \rho = \frac{\partial^2 T_{ij}}{\partial x_i \partial x_j} \tag{1}$$

Where, P is pressure, T is time, is medium density, C is sound propagation velocity in medium, is Lighthill turbulent stress tensor, v ρ $T_{ij} = \rho v_i v_j + p_{ij} - c^2 \rho \delta_{ij}$ i,vjIs the velocity component of the fluid and the function. $\delta_{ij} = \begin{cases} 0(i \neq j) \\ 1(i = j) i, j = 1,2,3 \end{cases}$B

The equation contains the terms of fluid flow and sound wave, thus explaining the problem that the flow process itself can produce sound waves, and thus explaining the acoustic mechanism of jet noise.

Lighthill used dimensional analysis to get the eighth power law of velocity or U8 law. The sound power of the jet noise is expressed as

$$W = \frac{K d^2 \rho_0 U^8}{c^5} \tag{2}$$

Where, K is Letterhill constant, D is nozzle diameter, P0 is medium density, and U is injection velocity.

Lighthill's eighth power law strictly obeys the eighth power law only in the vertical direction of the gas injection, but its simple form has played an important guiding role in the aerospace field over the past half century.

If the velocity is high, lighthill's eighth power law of velocity cannot be measured accurately. Based on this defect, ma Dayou, a famous scholar, used pressure instead of airflow velocity to obtain the sound power of jet noise, and put forward a pressure law similar to U8 law. The law of sound power-pressure can be converted from Lighthill's eighth power law of velocity:

$$W = 8Kd^2 \frac{(P_1 - P_0)^4}{\rho_0 c P_1^2} \tag{3}$$

P type1Is the upstream pressure of the valve, P0Is the downstream pressure of the valve.

Combined with Lighthill aeroacoustic equation and relevant sound power law, valve leakage is actually a kind of jet flow process, which is deduced from Boyle's theorem, ideal gas equation and Valve manufacturing manual written by Lu Peiwen []:

$$W = \beta \frac{6.9P}{D^{14}c^5RT}(\frac{Q}{\eta\alpha})^8 \tag{4}$$

Where, is the correlation coefficient, is the temperature, R is the gas constant, is the nozzle coefficient,, is the specific heat capacity ratio of the fluid, g is the gravitational acceleration. β

T η $\alpha = \sqrt{g\gamma(\frac{2}{\gamma+1})^{\frac{\gamma+1}{\gamma-1}}}$ γ

The root-mean-square value of ACOUSTIC emission signal and the sound power of gas jet noise are equivalent to:, then equation (4) is converted to: $AE_{rms}^2 = \mathrm{f}(W)$

$$AE_{rms}^2 = \mathrm{f}(\beta \frac{6.9P}{D^{14}c^5RT}(\frac{Q}{\eta\alpha})^8) \tag{5}$$

From the expression (2.14), the functional relationship between the root mean square (rmsAE) of the leakage signal and the main factors such as valve diameter D, pressure difference P between the upper and lower reaches of the valve, leakage flow Q in the valve gas volume, and temperature (T) at test time was obtained.

3. Processing and Inversion of Leakage ACOUSTIC Emission Detection Signal In Ball Valve

3.1. Experimental Device

In order to verify the rationality of leakage in the acoustic emission detection ball valve, the principle verification experiment was carried out by using the original verification device, as shown in FIG. 3.

Fig 3. Proof-of-principle verification device

The fluid is fed into the device by a motor, and the leakage of ball valve of different degrees is simulated by adjusting the opening degree of ball valve 1, and the valve cavity is simulated by the tank. The ACOUSTIC emission sensor is installed on the tank through the coupling stage, and the pressure difference on both sides of the valve body is controlled by adjusting the motor speed, so as to explore the relationship between acoustic emission signal and the leakage rate. Asmy-6 ACOUSTIC emission detection system was selected as the detection equipment, as shown in FIG. 4, with a sampling frequency of 400KHz.

Figure 4. ASMY-6 ACOUSTIC emission detection system

3.2. Denoising of Acoustic Emission Signals

Ball valve leakage in the frequency of the acoustic signal is usually 20 k - 200 KHZ, but in actual measuring process can make a big noise environment, especially the noise emitted by motor rotation, its frequency is low, can maintain the original signal through hardware low-pass filter in pure filter out the interference at the same time, also can keep the signals by means of software filtering of purity. CEEMDAN (full set empirical mode decomposition of adaptive noise) is used to process the collected amplitude signals in this paper.

The traditional EMD algorithm lacks the theoretical support of the system, resulting in some defects of EMD algorithm, such as endpoint effect and modal aliasing, etc. The appearance of modal aliasing will seriously affect the effect of EMD in signal processing, and to a large extent, restrict the practical engineering application ability of EMD. Based on improved EMD EEMD using gaussian white noise have uniform distribution of characteristic scales, by gaussian white noise in the signal to add some scale of the problem, to suppress the modal aliasing effect, but the inhibition effect is not complete, and is accompanied by the generation of multiple false component, at the same time, the addition of noise led to the increase of the reconstruction error, cannot balance effect and decomposition rate. CEEMDAN abandoned the process of adding noise decomposition for several times in EEMD and then calculating the mean value of

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each ORDER of IMF components to obtain the final IMF components. Instead, he obtained each order of IMF components by calculating the unique residual signal. The advantage of this method is that the residual random noise in each IMF order is averaged under the current order and will not be transmitted to the next IMF order.

The steps of CEEMDAN algorithm are as follows:

Suppose you have any signal X(t), define the operator Ek(*) is the KTH IMF obtained from EMD decomposition, IMFkIs the k IMF component obtained by CEEMDAN decomposition, i(t) for the gaussian white noise sequence added at the first time, i kIs the signal-noise ratio coefficient.

(1) CEEMDAN algorithm obtained the first IMF component in the same way as EEMD, and obtained the new signal sequence X(t)+ by adding noise to the signal X(t)0Omega.i(t) The first order IMF component IMF was obtained by EMD decomposition1, the expression is:

$$IMF_1(t)=\frac{1}{I}\sum_{i}^{I}IMF_1^i(t) \tag{6}$$

(2) Obtain the unique residual signal R in stage 11(t), the expression is:

$$r_1(t)=X(t)-IMF_1(t) \tag{7}$$

(3) At the first margin signal R1Add the noise component to (t) and you get R1(t) + epsilon1E1(omega.i(t)), continue the decomposition test until the first component is obtained, and calculate the second IMF component obtained by CEEMDAN, which can be expressed as:

$$IMF_2(t)=\frac{1}{I}\sum_{i-1}^{I}E_1(r_1(t)+\varepsilon_1 E_1(\omega^i(t))) \tag{8}$$

(4) According to step (3), the remaining stage (k=2...,K), and the K +1 IMF component obtained is:

$$r_k(t)=r_{k-1}(t)-IMF_k(t) \tag{9}$$

$$IMF_{k+1}(t)=\frac{1}{I}\sum_{i=1}^{I}E_1(r_k(t)+\varepsilon_k E_k(\omega^i(t))) \tag{10}$$

(5) Repeat the step (4) until the residual signal can no longer be decomposed by EMD. At this time, CEEMDAN algorithm is finished, and signal X(t) is decomposed by CEEMDAN into:

$$X(t)=\sum_{k=1}^{K}IMF_k(t)+r(t) \tag{11}$$

CEEMDAN algorithm was used to filter the collected amplitude signals, as shown in FIG.5. The signal-to-noise ratio of the signal after denoising and the signal before denoising was 8.61.

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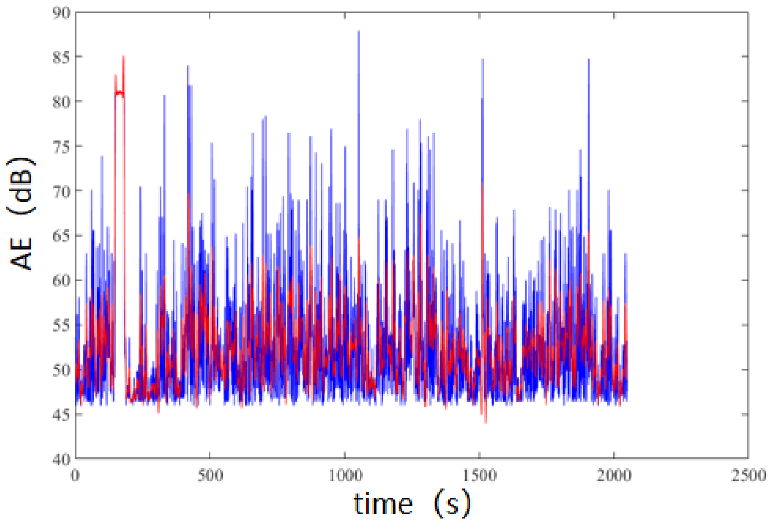

Fig 5. Signal denoising of CEEMDAN

3.3. Inversion of Leakage Rate in Ball Valve

Table 1. Characteristic values and corresponding leakage rate of acoustic emission signal in ball valve

The serial number	Pressure difference (MPa)	Peak value (dB)	RMS(dB)	ASL (v)	Leakage rate (L/min)
1	0.51	85.65	75	0.44	78.12
2	0.5	85.55	74.98	0.43	77.53
3	0.48	85.77	75	0.44	75.07
4	0.47	84.92	75	0.4	71.37
5	0.46	84.95	74.23	0.4	70.42
6	0.45	84.58	74	0.39	68.35
7	0.44	84.39	74	0.38	67.2
8	0.42	83.69	73.04	0.35	63.67
9	0.4	83.21	73	0.33	63.55
10	0.37	81.8	71.07	0.28	56.73
11	0.34	80.91	70.34	0.25	53.45
12	0.33	80.53	70	0.24	51.67
13	0.32	80.09	70	0.23	51.2
14	0.3	79.22	69	0.2	48.27
15	0.28	78.2	68	0.19	46.03
16	0.26	77.25	67	0.16	43.07
17	0.25	76.51	66	0.15	41.17
18	0.23	75.38	65	0.13	38.53
19	0.22	74.42	64	0.12	36.83
20	0.21	73.67	63	0.11	35.75
21	0.2	72.86	62.39	0.1	35.05
22	0.19	72.03	61.84	0.09	33.32
23	0.18	71.15	61	0.08	32.02
24	0.17	70.27	60	0.07	31.48
25	0.16	68.99	59	0.06	28.97
26	0.15	67.95	58	0.06	28.97
27	0.14	66.91	57	0.05	27.15
28	0.13	65.72	55.1	0.04	25.45
29	0.11	52.27	52.27	0.03	22.27
30	0.1	61.47	51.03	0.03	21.12

The acoustic signal generated by leakage in the ball valve is continuous AE signal, and the characteristic quantity of instantaneous AE signal, such as rising time duration, is not applicable to the inversion of internal leakage rate. Meanwhile, the signal frequency of leakage in the ball valve usually presents broadband characteristics, and the characteristic frequency is not outstanding enough. Therefore, in this paper, peak value, RMS (effective value voltage) and ASL (average signal level) are selected as the characteristic quantities of AE signals, and the leakage rate inversion of ball valve is studied in connection with the pressure difference between front and back of ball valve. The eigenvalues obtained through the experiment and the corresponding internal leakage rate are shown in Table 1.

In this paper, SVR (Support vector regression machine) algorithm is used for data training and inversion. Compared with traditional neural network, support vector machine has the following advantages:

Support vector machines can theoretically solve the local optimal problem of traditional neural networks.

The traditional neural network structure needs to be tried and tested repeatedly. Since the support vector of support vector machine determines the topology of support vector machine, this problem can be solved.

Support vector machine (SVM) maps variables to high-dimensional feature space, and classification in high-dimensional feature space can solve the dimension disaster.

Traditional neural networks require a large number of training samples, while support vector machines (SVM), which is a theory of machine learning rules for small sample problems, can obtain the optimal solution with limited samples.

The first 24 groups are taken as the training set, and the last 6 groups of data are taken as the test set. The test set results are shown in Figure 6.

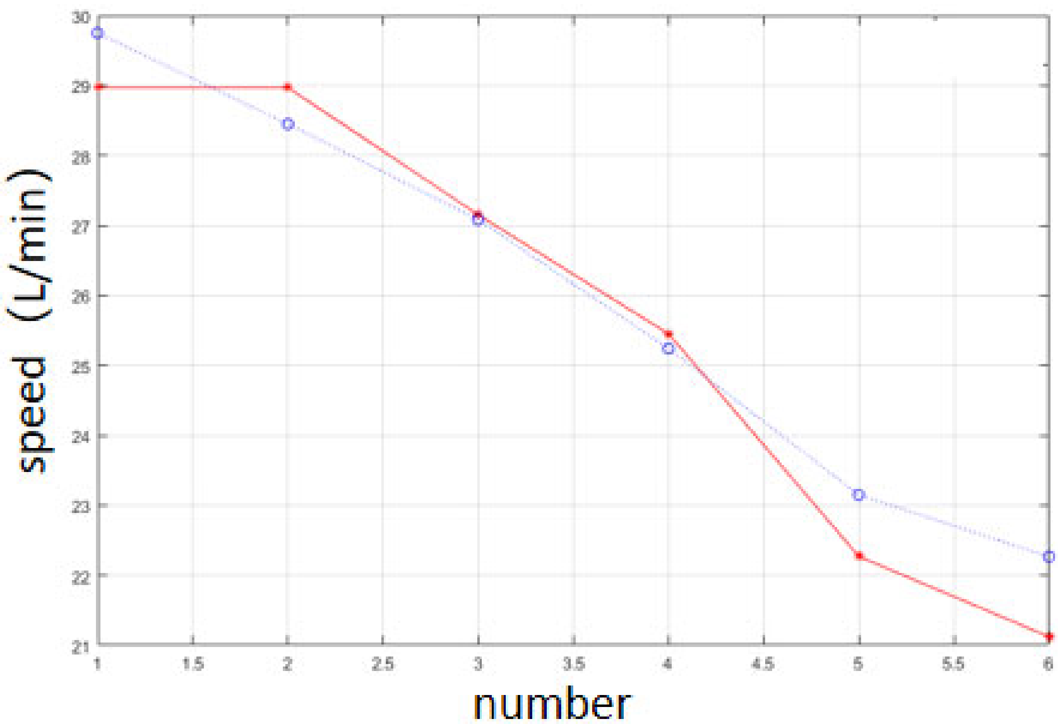

Figure 6. SVR test set inversion results

The inversion results are shown in Figure 7. The overall mean square error of the leakage amount is 3.22 and the correlation coefficient is 0.9842, showing a high correlation.

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4. Conclusion

Through the investigation and study of ae mechanism, the functional relationship between ae signal characteristic value and major factors such as valve diameter D, pressure difference P between upstream and downstream of the valve, leakage flow Q in valve gas volume and temperature (T) at test time was obtained, which theoretically explains the possibility of AE detecting leakage in ball valve.The rationality of acoustic emission detection of leakage in the ball valve was verified through experiments, and the leakage rate of the ball valve was inverted. CEEMDAN algorithm was applied to denoise the collected amplitude signals, and the signal-to-noise ratio was 8.61. The peak value of ACOUSTIC emission signal, RMS (effective value voltage) and ASL (average signal level) were extracted as characteristic values. Combined with the upstream and downstream pressure difference of the ball valve, SVR was applied to invert the leakage rate of the valve. The overall mean square error of the test set was 3.22, and the correlation coefficient was 0.9842.

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