Influence of Sampling Frequency in DCPD Crack Monitoring

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Abstract. Due to the particularity of autoclave environment, it is difficult to real-time monitor the crack growth state in the autoclave, and Direct Current Potential Drop method (DCPD) is widely in the crack propagate monitor in this kind experiment. The signal characterized by DCPD method is usually submerged by strong noise. In this paper, the extraction and filtering methods of crack characteristics in high temperature and high pressure environment are studied. The SINC filter is used to obtain crack initial data information and filter out the pulse interference signal, and the FIR filter is used to filter out high frequency interference. Finally, crack monitoring experiments at different sampling frequencies were studied. The experimental results show that the sampling frequency has a great influence on the stability and anti-interference ability of the data.

1. Introduction

The key issue that must be overcome in nuclear power plant life extension is that environmental cracking represented by Stress Corrosion Cracking (SCC), it reduces the design life and safety of nuclear power equipment[1]. It is one of the important experiment to obtain the stress corrosion cracking growth rate in an autoclave simulated the high temperature and high pressure water environment of the nuclear power equipment in the nuclear structural materials selection and safety evaluation. Due to the particularity of autoclave environment, it is very difficult to detect and monitor cracks. At present, the potential drop method (DCPD)[2] is the most effective indirect measurement method for crack length applied in high temperature and high pressure environments[3-4]. Compared with the AC potential drop method (ACPD)[5], the DC potential drop method (DCPD) has no skin effect. The existence and size of internal defects of the material are inferred by detecting the potential changes on both sides of the crack[6]. This technology was applied to nuclear power materials by P.L.Andresen et al.[7-8], they simulated the actual environment and studied the crack propagation of the material. The DC potential drop method was used by I.Černý[9] for experimental monitoring of some large pipeline components under high temperature conditions, he studied the initiation and propagation of crack defects in pipeline components, and took large pipeline specimens as an example. It was proposed to carry out certain temperature compensation and irregular area correction during the test, and the influence of crack closure should be considered.

The DCPD method monitors the crack signal is weak, it is difficult to extract and filter the signal in an autoclave environment, because noise is superimposed on weak signals. The method of FIR filtering to eliminate observation noise in GPS dynamic monitoring was proposed by Fengbo Wu[10], and he proposed a method based on FIR filtering for frequency shift filtering of high frequency signals. SINC3 filter designed by Xiaohang Wang[11], the method effectively filters out high
frequency noise and impulse noise. In this paper, the crack monitoring of 304 steel is studied, and the FIR filter algorithm is used to filter out the high frequency interference signals in the crack signal, and SINC filtering is used to eliminate spikes. We use the test instrument developed by ADS1235 chip as the terminal for data acquisition. We choose different sampling frequency, and find out the best filtering algorithm, and improve the accuracy and stability of the instrument.

2. Potential drop method for monitoring weak signal principle

The DC potential drop method is based on the detection method of the conductive properties of metal materials. When the CT sample is supplied with a constant current, as the crack length increases, the potential at both sides of the crack increases, but its potential changes have nonlinear characteristics. The Johnson formula gives a function to characterize the relationship between the crack size and the potential drop, this method is used to describe the length of the crack. Figure 1 shows a schematic diagram of the DCPD measurement principle of a crack-containing sample. The solution of the potential drop is shown in Equation 1:

\[ U = U_1 - U_2 \]  

In the formula: U is the potential drop, U1 and U2 are the two measuring point potentials.

For the infinitely long finite-width plate center crack specimen, the relationship between potential drop and crack length is given by Johnson's formula:

\[ U = \frac{4 \rho I}{\pi B} \cosh^{-1} \left[ \cosh \left( \frac{\pi a}{2W} \right) / \cos \left( \frac{\pi a}{2W} \right) \right] \]  

In the formula: a is the length of the crack half length, y is the half length of the distance between the two sides, W is the half width of the sample, B is the width of the sample, U is the potential difference between the two points, and I is the current intensity.

For compact tensile specimens (CT), the applicability of the Johnson formula in CT samples was analyzed by Chenqiang Ni [12], which pointed out that in terms of boundary conditions, the position of the input current point is no longer equivalent to the "distal" to the crack tip. At the same time, the position change of the current input point will have a considerable influence on the potential field distribution and the corresponding crack potential calibration function, and propose the most reasonable wiring point layout scheme [13]. As shown in Figure 1, the nuclear welding material of 304 steel was used as the research object, and a constant 1A current was passed at both ends. Monitor potential changes at both sides of the crack, the physical object is shown in Figure 3. Using a CT specimen with a pre-crack length of 1 mm, the voltage signals on both sides of the crack were...
measured, and the effects of the instrument on the weak signal acquisition were compared at different sampling rates.

As shown in Figure 2, according to the results of finite element analysis[14], it can be seen that the crack length is from 0.3m to 0.7m, and the potential change is 70uV. The results show that the relationship between the crack length and the potential drop is nonlinear, which verifies the consistency and accuracy of the finite element analysis and the Johnson formula.

3. Small signal detection algorithm

The small signal detection algorithm has multiple filtering measures. Firstly, the FIR signal is used to separate the high frequency interference from the low frequency crack characteristic signal. Then the SINC filter is used to filter the pulse interference, and the potential signal characterizing the crack length is obtained. Finally, the algorithm is used. The error analysis shows the sampling frequency with the best stability of DCPD crack monitoring. The algorithm flow is shown in Figure 3.

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![Algorithm Flow Diagram](image_url)

**Figure 3.** Algorithm flow

3.1. FIR Adaptive Filtering Algorithm

According to the characteristics of DC potential drop method, the useful signals are all in the DC component. Most of the interference comes from 50Hz/60Hz power frequency interference and random noise. These interferences are high frequency interference. The FIR filter works in low-pass mode, and it needs to filter out high-frequency interference to meet the design criteria of the filter circuit. There are many FIR filter algorithms, The minimum mean square error criterion adaptive algorithm is small in computation and easy to design and implement. Used in all kinds of filtering occasions. Due to the weak signal, differential circuits are used to acquire signals, according to the basic formula of FIR (3):

\[
Y(i) = \sum_{k=0}^{n-1} W(k) \cdot X(k-i), i = 0, \cdots, M
\]  \hspace{1cm} (3)

\( W(k) \) is the filter weight coefficient, the best design principle is that the sum of the squares of the error sequence is the smallest:

\[
\varphi = \sum_{i=0}^{M} e^2(i) = \sum_{i=0}^{M} d^2(i) - \sum_{k=0}^{N-1} \sum_{j=0}^{N-1} w(k)w(j)r_{ij}(k-j)
\]  \hspace{1cm} (4)

In the formula: \( r_{ij} \) the relationship between the expected signal and the input signal Describe the formula \( r_{xx} \) is the autocorrelation coefficient of the input signal.

\[
\frac{\partial \varphi}{\partial w(k)} = 0,0 \leq K \leq N-1
\]  \hspace{1cm} (5)

Minimum principle based on squared sum of error sequences
\[ w_{i+1} = w_i(k) + 2\mu e(n)x(i+k), i = 0, 2, \ldots, M \]  

The main determinants of the convergence speed of the iterative step size and the filter order. It can theoretically be any value. In the actual calculation, the initial value of the weighting value is zero. For the filtering order, the general filtering order is higher. The better the convergence range of the filter is, the stricter the convergence condition is. The optimal length of the different signals is different. Generally, the selection is based on experience. Generally, the length is set to be larger.

3.2. SINC filtering algorithm
The potential signal characterizing the crack length is filtered by FIR, and the high frequency signal interference is filtered out. Due to the special environment in the autoclave, the experimental results show that there is a random pulse signal as shown in Figure 4. In order to filter out the pulse interference, SINC filter is used, the SINC filter has no excessive bandwidth, which limits the signal content that the filter can measure. According to the technical characteristics of the DC potential drop method, the useful signal is a DC component. It is just right to solve the filtering of such signals. As shown in Figure 4, the test result is filtered after SINC filter.

![Figure 4. Comparison before and after filtering](image)

4. Experiment and analysis

4.1. Effect of sampling frequency
In this experiment, the 34420A nanovoltmeter of Keysight Technology was used as the experimental comparison. The design instrument based on ads1235 chip was used as the acquisition equipment, and the acquisition rate was adjusted from 2.5SPS to 7200SPS. For the same CT sample measured for 60s, after a lot of experiments, The sampling frequency has a great influence on the instrument test results, and the data fluctuates between 5uV and 15uV. The result is shown in Figure 5.

The stability of the instrument is related to the sampling frequency. The test results of the instruments at different sampling frequencies have large differences. Although the FIR filter filters out high-frequency interference, the SINC filter filters out the pulse signal, and there are still 11 kinds of sampling frequencies with data fluctuations around 15uV. The data fluctuation is around 0.2uV and the sampling frequency is 400SPS and 5SPS. According to the theoretical calculation, the CT signal with a crack length of 1 mm has a crack potential signal of 6 uV. As can be seen from Figure 6, the different sampling frequencies make a large change in the accuracy and stability of the instrument acquisition results. The weak signal and the interference signal are superimposed together, and the peak-to-peak voltage of the collected voltage is about 15uV, which greatly affects the crack monitoring accuracy. According to the theoretical calculation, the crack growth 1mm potential signal changes to 3uV, therefore, the instrument signal fluctuation is 1uV. The best resolution of the instrument.

As shown in Figure 6, the sampling frequency is less fluctuating at 400 SPS and 5 SPS, and the fluctuation range is 1 uV, which can meet the acquisition accuracy of the crack monitoring instrument.
Both sampling frequencies can meet the accuracy requirements of the instrument test. The stability of the data is an important indicator of the constant instrument [15]. The stability of the variance analysis is used for the test data. The sampling frequency is 400SPS and the 5SPS variance results are $\sigma^2 = 0.001540321$ and $\sigma^2 = 0.006835235$ respectively. The results show that the stability is best when the sampling frequency is 400SPS in the short term.

4.2. Crack dynamic simulation experiment

The crack growth period is long, and the CT specimen cannot exhibit the crack propagation in a short time. In order to verify the instrument, a total of 10 CT samples with a crack length of 1 mm to 5 mm were prefabricated, and the dynamic growth of the crack was simulated by the contact relay switching. As shown in Fig. 7(a), the crack length is increased by 0.5 mm in turn, and a significant step signal can be seen on the graph. As with the finite element analysis, the voltage change of 4uV per 1mm crack is also consistent with the expected results. Figure 7(a) shows the comparison between Keysight's products and this product. The test results of foreign related instruments and the instrument are basically the same, and the data collected by the instrument is reliable. Figure 7(b) shows the sampling results of different dates. According to the analysis of the test results of six days, it is found that the stability of the instrument for a long time is high, but there are still fluctuations, and we will further improve the stability of the instrument.

5. Conclusion and future work

In order to test the environmental cracking crack growth rate of nuclear power structural materials in an autoclave simulating nuclear power high temperature and high pressure water environment, a crack monitoring instrument based on ADS1235 chip was developed, and FIR filtering and Sinc filtering are used in the acquisition of weak signals. The experimental results show that the proposed method not
only preserves the original signal characteristics, but also improves the accuracy and resolution of the monitoring system. According to the experiment, the following conclusions are obtained:

- The FIR filtering algorithm used in the microvolt signal monitoring process has a good suppression effect on the high frequency signal, and the SINC filtering algorithm has a good filtering effect on the pulse signal.
- Microvolt-level signal acquisition, the change of sampling frequency has a greater impact on the stability and accuracy of the measured data.

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