Application of Lock-in Amplifier Technique in AC FSM based on AD630

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Abstract. Field Signature Method (FSM) is one of non-intrusive technique for pipeline internal corrosion monitoring, but the commercial FSM systems nowadays are all using DC input which have many shortcomings. In this paper, AC FSM based on AC input has been developed, DC FSM can be replace by AC FSM with low-frequency. To extract weak signals, the lock-in amplifier based on AD630 has been designed and manufactured, the functions and designed circuits of each part have been proposed. Experimental results show that, the application of lock-in amplifier technique in AC FSM based on AD630 can measure the weak signal from the noise interference effectively, ensuring the accuracy and security at the same time.

1. Introduction
Field Signature Method (FSM) is one of advanced technique of pipeline internal corrosion monitoring for large surface areas, which is a non-intrusive method that means all the equipment are placed on the outside of the pipelines\(^1\). The commercial systems that have been used for industrial applications are all based on DC FSM, a large DC input is needed to produce a measurable signal, which will cause heating in the monitoring area, giving rise to significant uncertainty in assurance and measurement\(^2\). In this paper, AC FSM based on AC input has been developed to avoid the high current values. The numerical analysis and simulation show that in corrosion monitoring the AC FSM can provide more information than DC FSM, AC FSM with low-frequency can be used as DC FSM and prevent the problems caused by large currents.

To extract weak signals, a lock-in amplifier based on AD630 has been designed and manufactured, which is cheaper, small in size and flexible. Experimental results show that, the application of Lock-in amplifier technique in AC FSM based on AD630 can measure the weak signal from the noise interference effectively, ensuring the accuracy and security at the same time.

2. The analysis of AC FSM

2.1 The principle
The principle of AC FSM is based on the measurement of increase in electric resistance\(^3,4\), caused by presence of corrosion between measuring probes installed on the outside surface of the pipeline as shown in figure 1.
Figure 1. The FSM schematic diagram

When a given alternating current \( I \) inject in the pipeline, the electric field intensity can be calculated with the following equation \(^5\)

\[
E(r) = I \rho (2\pi r T(f))^{-1}
\]

(1)

Where \( \rho \) denotes the resistivity of the specimen, \( f \) denotes the frequency, \( T(f) \) denotes the skin-effect that expressed as \( T(f) = (\pi f \sigma \mu)^{-1/2} \), \( \sigma \) denotes the electrical conductivity, \( \mu \) denotes the magnetic permeability\(^6\).

When the plate thickness \( t \) is smaller than the depth of skin-effect, the critical value of the frequency can be deduced as equation 2. The electric resistance will not vary when the frequency below \( f_c \)\(^7\).

\[
f_c = (\pi \sigma \mu^2)^{-1}
\]

(2)

2.2 The simulation

Current distribution of AC FSM in intact specimen at three different frequencies, which were 1Hz, 20Hz, 100Hz, was illustrated the figure 2. It can be noticed that, as the frequency increasing, the current was squeezed to the metal surface through the skin effect. The AC FSM with low-frequency can achieve the same result against DC FSM, which means that AC FSM with no need for high current injection by controlling the frequency.

Figure 2. The current distribution at three different frequencies

3. The design of lock-in amplifier based on AD630

3.1 The principle

The signals of interest extract from the pipeline are extremely small, and the lock-in amplifier has been adopted to recover small signals from strong interfering noise. The heart of the lock-in amplifier is the phase-sensitive detector (PSD), multiplying the signal and reference signal together\(^8, 9\).

Considering a signal \( x(t) = V_s \cos(\omega_0 t + \theta) \) is being detected, and the reference signal is \( r(t) = V_r \cos(\omega_f t) \), where \( \omega_0 \) denote the frequency of the signal, \( \theta \) denote a phase-shift with respect to a reference signal. So the PSD output voltage is given by\(^10-12\):

\[
u_p(t) = x(t) r(t) = V_s \cos(\omega_0 t + \theta) V_r \cos(\omega_f t) = 0.5V_s V_r \cos \theta + 0.5V_s V_r \cos(2\omega_f t + 2\theta)
\]

(3)

The reference signal is passed through a phase shifter before being applied to the PSD, which is used to compensate for phase differences. The output from the PSD then passes to a low-pass filter to removes the \( 2\omega_f \) component and the leaving component is in direct proportion to \( V_s \)\(^13\).
3.2 The design of lock-in amplifier based on AD630

The block diagram of a lock-in amplifier based on AD630 is shown in figure 3. The main function of this lock-in amplifier is extracting the amplitude information of the signal to evaluate the corrosion status of the pipeline. For the phase information is known and fixed, and then the desired signal can be obtained through the integrator and low-pass filter following the AD630, these three parts compose the lock-in amplifier.

![Lock-in amplifier block diagram](image)

Figure 3. The block diagram of lock-in amplifier

The AD630 was chosen to be used as the PSD in the lock-in amplifier configuration. AD630 is a high precision balanced modulator, its configuration makes it ideal for signal processing applications. The PSD electric circuit based on AD630 is shown in figure 4. The monitoring signal finished spectrum shifting by passing the AD630, two components have been generated, that are the low-frequency component with the available information and the high-frequency component that need to be reject. The integral circuit adopted AD708 as the core chip, the figure 5 shows the electric circuit. And the following low-pass filter will reject the high-frequency component and most of the noise. The AD708 is used in low-pass filter configuration, and the positive feedback was introduced at the output capacitor, the electric circuit is shown in figure 6. Then the noise that accompanied with the input signal can be removed on the whole by the lock-in amplifier based on AD630.

![Electric circuit of PSD](image)

![Electric circuit of integrator](image)

![Electric circuit of low-pass filter](image)

Figure 4. The electric circuit of PSD

Figure 5. The electric circuit of integrator

Figure 6. The electric circuit of low-pass filter

4. Experiment

For the experimental tests, pictured in figure 7, a flat-bottomed 620×240×5mm carbon steel plate was used. The electrical properties of the plate are $\sigma=5.0 \times 10^6 \Omega^{-1} \cdot m^{-1}$, $\mu=100$. To test the capability of measuring the mixed signal by the lock-in amplifier designed in this paper, three signals with the same amplitude and different SNR were input, that were pure signal, SNR=1:10 signal, SNR=1:50 signal. The variances of lock-in amplifier output between SNR=1:10 signal and pure signal, SNR=1:50 signal and pure signal were calculated and shown in figure 8, it can be seen that variances are all within acceptable limits, which means the lock-in amplifier based on AD630 can measure the signal with noise interference effectively, verifying the stability of the system.

To test the precision of the lock-in amplifier based on AD630 designed in this paper, the instrument Stanford Research SR830, which was a digital lock-in amplifier that can provide high performance in weak signal measuring, was used as the benchmark. An AC with an amplitude of 1.5A was input, the relative error and the error of measurements between designed system and the SR830 were shown in figure 9, that are all keep within a small range. The conclusions can be drawn that the designed system...
can ensure the accuracy and security at the same time.

The transfer resistance was measured by the lock-in amplifier designed based on AD630 on the plate over a broad range of frequencies, from 1 Hz to 100 Hz, the results are plotted in Fig. 10. When the depth of skin-effect is larger than the thickness of the tested plates, the transfer resistance measured on the plate does not vary with frequency. On the other hand, it can be noticed that at high frequencies, when the depth of skin-effect is smaller than the plate thickness, the resistance increases with frequency, which is validated by both simulation and experiment results.

5. Conclusion
In summary, we applied lock-in amplifier technique in AC FSM based on AD630, the functions and circuit design of each part were proposed and verified experimentally. The simulation and experiment results showed that, the lock-in amplifier designed can measure the weak signal even in the condition of SNR=1:50, and the variances are within acceptable limits. The conclusion can be reached that the designed system can ensure the accuracy and security at the same time by comparing the measuring result with SR830. The experiment results of transfer resistance measurement are in good agreement with numerical analysis and simulation. All of above show the effectiveness of this method.

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