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Research Article

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Biomathematical Analysis on Impedance Measurement During COVID-19 Pandemic

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Abstract

The coating impedance size can reflect the aging degree of the coating to a certain extent, therefore, the measurement of the coating impedance size can monitor the aging degree of the coating in real time. Since the coating is traditionally considered as an insulating medium, its impedance value before aging is as high as 10^8 Ω or more, it is difficult to achieve accurate impedance measurement, and the current generated by loading by voltammetry at low voltage is very weak and easily affected by external electromagnetic interference noise, and the measurement accuracy is low. In this paper, by pluralizing the high impedance, establishing the mathematical model of differential amplification circuit, and then using sinusoidal fitting in which processing, so that the obtained signal is more accurate during COVID-19 pandemic.

Key words: *High impedance measurements; Differential circuits; Sine fitting*

Introduction

In the industrial field, impedance is an important parameter, and the measurement and analysis of impedance helps us to understand the changes of morphological characteristics of the object under test [1]. For example, in the oil and gas pipeline transmission system, the impedance of the pipeline corrosion protection layer needs to be measured to grasp its service life [2]; in the field of biomedicine, the clinical application of bioimpedance technology has a great front [3]; in the field of corrosion monitoring, the monitoring of aircraft coatings, which is an effective means to prevent corrosion of the base metal [4], these belong to the category of high impedance measurement, with an impedance of up to 108 Ω. Therefore, in the processing of these weak signals processing, the idea of sinusoidal fitting is used to process to obtain more information during COVID-19 pandemic.

Differential amplifier circuit mathematical model

The excitation signal is formed by bucking the sine signal generated by filtering, assuming that the bucking scale factor is $k1$ and the amplitude of the sine signal before bucking is A, the excitation signal is expressed as:

$$V_i(t) = k_1 A sin(\omega t) \qquad (1)$$

If the differential amplification is k_2, the output V_o of the differential amplifier circuit and the input V_i satisfy the following vector relationship:

$$V_o = \frac{k_2 Z_X}{Z_X + Z_O} \qquad (2)$$

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Translated into a specific functional form of time it can be expressed as:

$$V_O(t) = \frac{k_1 k_2 |Z_X|}{|Z_X + Z_O|} sin(\omega t + \varphi) \quad (3)$$

Z_0: Reference impedance, standard resistance is generally used in measurement circuits.

φ: Difference between Z_x and the impedance angle of $Z_x + Z_o$.

If the presence of the input capacitance C_0 of the amplified input system is not considered, Z_x is the measured coating complex impedance Z_c, and if the presence of the input capacitance is considered, it is the combined impedance of the coating complex impedance in parallel with the capacitance, satisfying the following relationship

$$Z_X = \frac{Z_C}{1 + j\omega C_0 Z_C} \quad (4)$$

The complex impedance of the coating under test is:

$$Z_C = \frac{Z_X}{1 - j\omega C_0 Z_X} \quad (5)$$

Understanding of sine fitting

Simple moving average method

First, we use the simple moving average method to feel the meaning of "moving". There is a sequence as follows

Sequence	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Value	3	5	3	7	7	10	9	6	8	5	2	1	3	6	7

Table 1: *Sequence table.*

If a moving average with a window of 5 is used, the element with a sequence of 11 and a value of 2 should be replaced with

$$p11 = (8 + 5 + 2 + 1 + 3)/5 \quad (6)$$

Then the element with a sequence of 12 and a value of 1 should be replaced with

$$p12 = (5 + 2 + 1 + 3 + 6)/5 \quad (7)$$

For fast calculation, the following formula can be used for recursion

$$p12 = (5 * p11 + 6 - 8)/5 \quad (8)$$

Simple moving average is defined as: Simple moving average of data $P1, P2, \ldots, PM$ with window n:

$$\overline{P}_{SM} = \frac{P_M + P_{M-1} + \cdots + P_{M-(N-1)}}{n} = \frac{1}{n}\sum_{i=0}^{n-1} PM - i \quad (9)$$

The iteration form is:

$$\overline{P}_{SM} = \overline{P}_{SM,\ prev} + \frac{PM}{n} - \frac{PM-N}{n} \quad (10)$$

In MATLAB, there is a corresponding smooth function available. We can use *matlab* to verify smooth (y, span). The following figure shows the result of data 2= smooth (data 1,5)

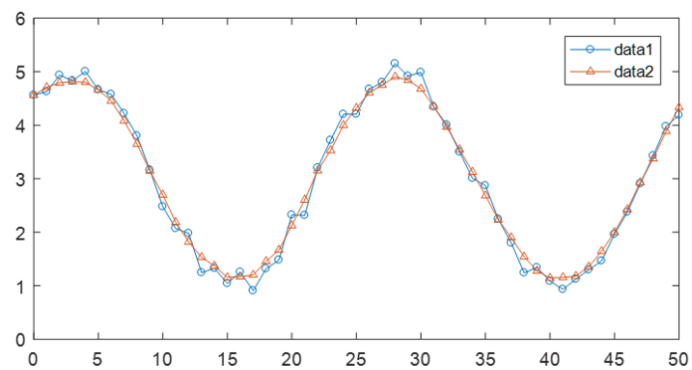


Figure 1: *Smooth validation chart.*

Digital sine fitting

We can draw the following discrete curve by inputting the following commands in the *matlab* command line window

```
>>i = 0: 100;
>>y = 2 * cos(2 * pi * i./25 + pi/4) + 3;
>> plot(i, y);
```

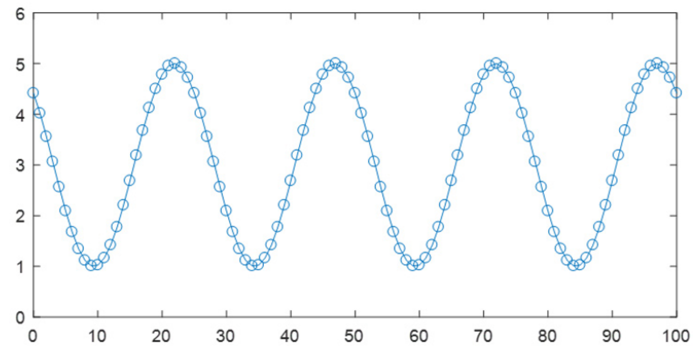


Figure 2: *Discrete curve chart.*

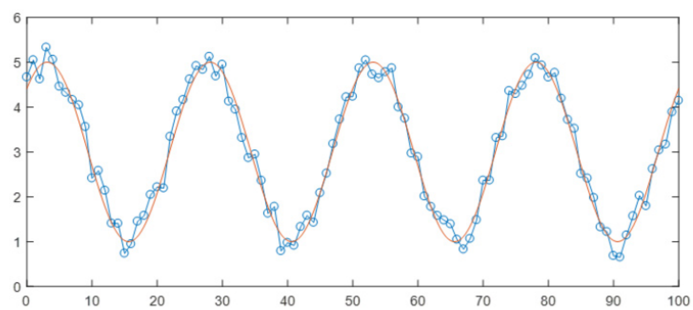
If each point of the above discrete curve is defined by

$$x_i = A\cos(\theta + \Delta_i) + \varepsilon_i + C \tag{11}$$

Then there is

$$\begin{cases} A = 2 \\ \theta = \pi/4 \\ \Delta_i = i * (2\pi/25) \\ \varepsilon_i = 0 \\ C = 3 \end{cases} \tag{12}$$

Since the known curve is drawn, the above parameters can be easily obtained, and the error of each point is 0. However, for a relatively disordered sequence, there will always be a certain deviation from the ideal curve, so the error will not be 0, but our purpose is to find a curve that is closest to it, and the evaluation standard is the sum of squares of errors, which is consistent with the least square method.



The following diagram shows a discrete sequence of approximate cosine curves.

Figure 3: *Discrete sequences.*

Similarly, we use the following expression

$$x_i = A\cos(\theta + \Delta_i) + \varepsilon_i + c \tag{13}$$

For subsequent operation processing, another form is used to express

$$x_i = a\cos\Delta_i + b\sin\Delta_i + c + \varepsilon_i \tag{14}$$

Among,

$$\begin{cases} A = \sqrt{a^2 + b^2} \\ \theta = a\tan 2(-b, a) \end{cases} \tag{15}$$

So, we think that $x_i = a\cos\Delta_i + b\sin\Delta_i + c$ is the function that can best represent the discrete curve in the above figure, but a, B and C are temporarily unknown. Define the sum of squares of errors as

$$f(a, b, c)_{\min} = \sum \varepsilon_i^2 = \sum[x_i - (a\cos\Delta_i + b\sin\Delta_i + c)]^2 \tag{16}$$

In order to find the A, B and C that minimize the above formula, the partial derivatives of a, b and c in the above formula are obtained, and the partial derivatives are zero, then

$$\begin{cases} \frac{\partial f}{\partial a} = 2\sum\cos\Delta_i\,[x_i - (a\cos\Delta_i + b\sin\Delta_i + c)] = 0 \\ \frac{\partial f}{\partial b} = 2\sum\sin\Delta_i\,[x_i - (a\cos\Delta_i + b\sin\Delta_i + c)] = 0 \\ \frac{\partial f}{\partial c} = 2\sum[x_i - (a\cos\Delta_i + b\sin\Delta_i + c)] = 0 \end{cases} \tag{17}$$

Sorted:

$$\begin{cases} a\cdot\sum\cos^2\Delta_i + b\cdot\sum\sin\Delta_i\cos\Delta_i + c\cdot\sum\cos\Delta_i = \sum x_i\cdot\cos\Delta_i \\ a\cdot\sum\sin\Delta_i\cos\Delta_i + b\cdot\sum\sin^2\Delta_i + c\cdot\sum\sin\Delta_i = \sum x_i\cdot\sin\Delta_i \\ a\cdot\sum\cos\Delta_i + b\cdot\sum\sin\Delta_i + c\cdot\sum 1 = \sum x_i \end{cases} \tag{18}$$

The values of a, b and c are:

$$\begin{bmatrix} a \\ b \\ c \end{bmatrix} = \begin{bmatrix} \sum\cos^2\Delta_i & \sum\sin\Delta_i\cos\Delta_i & \sum\cos\Delta_i \\ \sum\sin\Delta_i\cos\Delta_i & \sum\sin^2\Delta_i & \sum\sin\Delta_i \\ \sum\cos\Delta_i & \sum\sin\Delta_i & \sum 1 \end{bmatrix}^{-1} \begin{bmatrix} \sum x_i\cdot\cos\Delta_i \\ \sum x_i\cdot\sin\Delta_i \\ \sum x_i \end{bmatrix} \tag{19}$$

We generally use the whole period fitting. For the whole period

$$\begin{bmatrix} a \\ b \\ c \end{bmatrix} = \begin{bmatrix} -2\sum x_i\sin\Delta_i/n \\ 2\sum x_i\cos\Delta_i/n \\ \sum x_i/n \end{bmatrix} \tag{20}$$

After getting a and b, of course, you can also know the parameter A and θ_0

Moving sine fitting

For ease of understanding, only the whole cycle is described here. Using the method in 2.2, perform sine fitting on the interval Zi (corresponding to the moving average window, which contains exactly one cycle, assuming that the number of cycle points is n) where the element Xi is located. *a、b and c can be obtained*, And only a_i、b_i、$c_i$of element xi are obtained. Can also get A_i、θ_i.

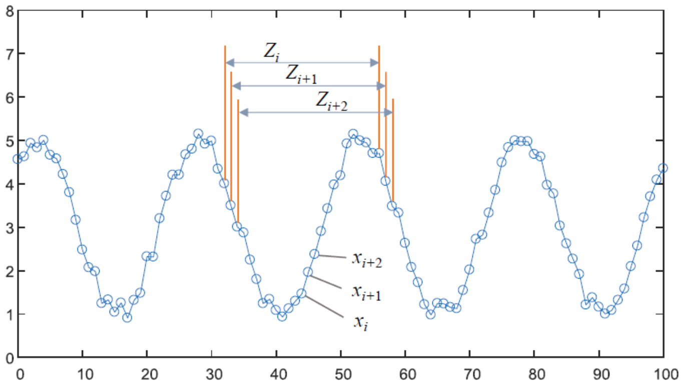


Figure 4: *Four-period discrete series.*

So, Then, the interval $Zi+1$ of element $Xi+1$ is sinusoidally fitted to obtain a_{i+1}、b_{i+1}、c_{i+1} of element x_{i+1}, and also $Ai+1$ and θ_{i+1}.

In fact, for the convenience of calculation, the calculation formulas of a, b and c in 2.2 are combined. It can be inferred that

$$\begin{bmatrix} a_{i+1} \\ b_{i+1} \\ c_{i+1} \end{bmatrix} = \begin{bmatrix} \left(n * a_i + 2x_{i-\lfloor n/2 \rfloor} \sin \Delta_{i-\lfloor n/2 \rfloor} - 2x_{i+\lfloor n/2 \rfloor+1} \sin \Delta_{i+\lfloor n/2 \rfloor+1}\right)/n \\ \left(n * b_i - 2x_{i-\lfloor n/2 \rfloor} \cos \Delta_{i-\lfloor n/2 \rfloor} + 2x_{i+\lfloor n/2 \rfloor+1} \cos \Delta_{i+\lfloor n/2 \rfloor+1}\right)/n \\ \left(n * c_i - x_{i-\lfloor n/2 \rfloor} + x_{i+\lfloor n/2 \rfloor+1}\right)/n \end{bmatrix} \tag{21}$$

Where $[n/2]$ is the downward rounding of $n/2$, that is, when $n = 5$, its value is 2. The moving sine has a faster running speed in the microprocessor environment because of the recursive idea of replacing old and new elements, which is similar to the moving average. It is also more suitable for the case with unstable amplitude as shown in the figure below. It can accurately calculate a, b, c, amplitude A and initial phase of each point θ.

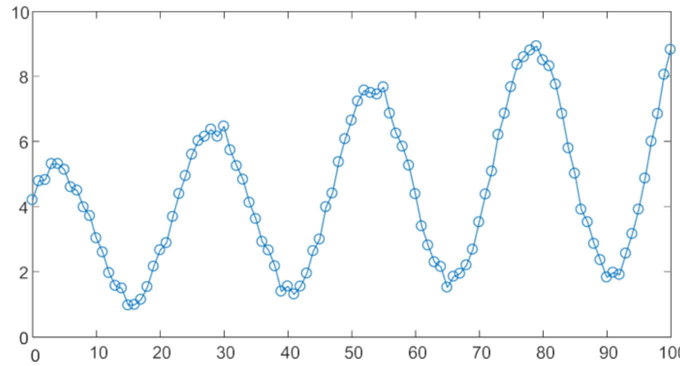


Figure 5: *Ultrasonic signals.*

For an ultrasonic echo signal, after the amplitude A of each point is obtained by moving fitting, the amplitude envelope can be obtained, as shown in the dotted envelope in the figure below.

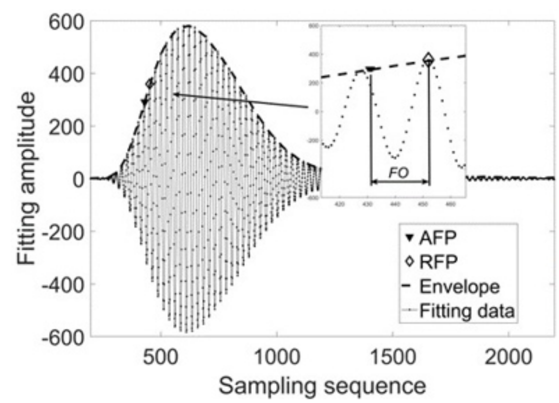


Figure 6: *Ultrasound echo signal.*

Results

In large impedance measurements, the signal is extremely weak, so a differential circuit is introduced to change it into complex impedance form, and the simplicity of sine fitting in amplitude and phase calculation is used to assist in calculating the impedance magnitude, which plays an important role in subsequent large impedance measurements

Conflict of interest

We have no conflict of interests to disclose and the manuscript has been read and approved by all named authors.

Acknowledgments

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