Research on the Technology of Conductor Corrosion Detection based on Eddy Current Testing

Zhongkai Xu¹, Yuancheng Zhu¹, Hongfeng Ma¹, Youzhong Duan¹, Changlong Yang² and Deyu Song²*

¹State Grid Yingkou Electric Power Supply Co., Ltd., Yingkou, Liaoning Province, 115000, China
²State Grid Shenyang Electric Power Supply Co., Ltd., Shenyang, Liaoning Province, 110004, China

*Corresponding author’s e-mail: songdeyu_cool@126.com

Abstract. The detection of conductor corrosion state provides technical guarantee for mastering the corrosion type, corrosion degree and service life of power transmission lines, realizing the timeliness and accuracy of power line replacement, and reducing the hidden danger of line safety. In this paper, a method based on eddy current testing for corrosion detection of power wire is proposed. High and low frequency eddy current testing is used to measure the residual cross-sectional area of wire, and the output database of flaw detection is established to deduce the residual tensile force of wire. Finally, by introducing the artificial single line sample and the actual running conductor for dynamic comparison, the residual tension data of the conductor can be corrected. The results show that the method adopted in this paper is feasible and accurate, which further guarantees the safe and reliable operation of overhead transmission lines.

1. Introduction
The corrosion atmosphere, humidity, temperature, wind speed and other environment around the overhead conductor will affect the corrosion degree and service life of the conductor, it is also closely related to the state characteristics of the conductor, such as conductor operating temperature, tension, fretting wear between wires, strong electromagnetic field, etc [1-3]. The detection technology of corroded conductor can clearly detect the corrosion information of the line and provide guidance and scheme for the replacement of conductor. However, the research on this kind of problem in China is still in its infancy [4-5]. In this paper, a method of corrosion detection of power line based on eddy current detection is proposed. The residual cross-sectional area of power line is measured by eddy current detection, and the residual pulling force is calculated by establishing the output database of flaw detection, so as to determine the corrosion degree and service life of power line, so as to provide technical guarantee for the safe operation of power line.

2. Eddy current testing technology
2.1 Principle of eddy current detection
Because the electromagnetic field around the conductor is generated by the electromagnetic circle, the conductor generates eddy current at the edge of the magnetic field in order to counteract the magnetic
field generated by the electromagnetic circle [6]. The size of eddy current varies according to the state of conductor. By measuring the size of eddy current, the state of conductor can be measured quantitatively. The magnitude of eddy current is determined by the change of electromagnetic coil caused by the interaction between conductors. As it is shown in Figure 1 below:

![Figure 1. Schematic diagram of eddy current testing](image)

2.2 Effective permeability

The impedance analysis of the detection coil is an important part of eddy current testing, which is complicated and difficult. In order to simplify the analysis process, the concept of effective permeability is proposed [7].

We suppose the radius of a circular conductor is a and the relative permeability is μ. A group of solenoid coils are tightly wound on the conductor. Assuming that the direction of the solenoid is in the positive z-axis direction, the alternating magnetic field \( H_z \), which changes along the radial direction, will be generated on the conductor when the current I is applied to the solenoid without considering the edge effect. Because of the skin effect [8], \( H_z \) decreases with the increase of the distance from the surface. The magnetic field induction strength in the conductor is:

\[
B_z(r) = \mu_0 \mu_i H_z(r)
\]  

(2.1)

Where \( r \) is the distance from any point in the wire to the axis, which can be obtained from the electromagnetic field theory:

\[
H_z(r) = A_1 I_0(\sqrt{jk}r) + A_2 K_0(\sqrt{jk}r)
\]  

(2.2)

Where \( I_0(\sqrt{jk}r) \) is the first kind of 0-order virtual Zong Bessel function; \( K_0(\sqrt{jk}r) \) is the second kind of virtual Zong Bessel function of order 0, and \( K_0 = \sqrt{\omega \mu \sigma} = \sqrt{\omega \mu \sigma} \); \( A_1 \) and \( A_2 \) are complex constants and \( \sigma \) is conductivity. From this, we can get:

\[
H_z(r) = H_0 \frac{I_0(\sqrt{jk}r)}{I_0(\sqrt{jk}a)}
\]  

(2.3)

Through formula 2.3, we can get the relationship between the magnetic flux \( \phi \) of any section of the conductor:

\[
\phi = \int B_z \, ds = \int_0^a 2\pi r \mu_0 \mu_i H_z(r) \, dr = 2\pi \mu_0 \mu_i H_0 \frac{a}{\sqrt{-jk}} \frac{J_1(\sqrt{-jk}r)}{J_0(\sqrt{-jk}r)}
\]  

(2.4)

\( J_0(\sqrt{-jk}r) \) and \( J_1(\sqrt{-jk}r) \) are Bessel functions of order 0 and 1 respectively.
For the above case, it is assumed that there is a constant magnetic field $H_0$ on the cross-section of the conductor, and the permeability changes along the radial direction on the cross-section, and the magnetic flux generated by it is equal to that generated by the physical place in the conductor. The constant magnetic field $H_0$ and the changing flux can be used to replace the changing magnetic field $H_z$ and the constant permeability $\mu$. The changing permeability is called the effective permeability, which is expressed by $\mu_{\text{eff}}$:

$$\mu_{\text{eff}} = \frac{2}{J_1(\sqrt{-jka})} \cdot \frac{J_0(\sqrt{-jka})}{J_0(\sqrt{-jka})}$$

(2.5)

2.3 Characteristic frequency

In the expression of effective permeability, the corresponding frequency is defined as the characteristic frequency when the modulus of virtual vector of Bessel function is 1, which is expressed as follows:

$$\sqrt{-jka} = \sqrt{2\pi f \mu \sigma a^2} = 1$$

(2.6)

According to formula 2.6:

$$f_g = \frac{1}{2\pi \mu \sigma a^2}$$

(2.7)

It is the inherent characteristic of the conductor, which depends on the electromagnetic characteristics and geometric size of the conductor itself.

3. Analysis of the application of eddy current testing in the conductor corrosion detection

The purpose of conductor corrosion detection is to determine the remaining life of conductor, and the reduction of tensile strength caused by corrosion should be analyzed. In this paper, the CASS experiment method (a method which can accelerate the corrosion is to add salinized copper and acetic acid in the salt spray solution). A single line sample of artificial corrosion which is close to the actual corrosion state is selected to determine the cross-sectional area and residual tensile strength and investigate the relationship between them, as shown in Figure 2 below:

![Figure 2. Relationship between residual sectional area and residual tensile force](image)

From the above figure, it can be concluded that there is a linear relationship between the residual cross-sectional area and the residual tensile force of the aluminum strand. The residual tensile force can be inferred from the residual cross-sectional area, which proves that the method of eddy current detection technology for measuring the residual cross-sectional area is feasible.
3.1 Eddy current inspection frequency

In order to infer the pulling force of the conductor from the residual cross-sectional area, it is necessary to detect the residual cross-sectional area of aluminum and steel respectively, and determine the most appropriate detection frequency. In this paper, two detection methods with different frequencies are used simultaneously. The output results of flaw detection at two different frequencies are shown in Figure 3 below:

![Figure 3. Flaw detection output of aluminum strand and steel core wire under different flaw detection frequency](image)

It can be seen from the above figure that the flaw detection output of aluminum strand is 0 when the low frequency flaw detection is below 200Hz, which means that the eddy current generated by aluminum strand is 0 in this frequency range, and only the steel core wire generates eddy current. With the increase of frequency, eddy current begins to be generated in the aluminum strand. When the high frequency range above 50kHz is reached, the flaw detection output of aluminum strand exceeds that of steel core.

Figure 4 shows the relationship between the residual cross-sectional area of 160mm² steel cored aluminum strand and the flaw detection output under the most appropriate flaw detection frequency.

![Figure 4. Relationship between flaw detection output and residual sectional area](image)

According to the above results, high frequency and low frequency can be used in eddy current testing of ACSR, high frequency can be used to flaw detection to measure the residual cross-sectional area of the whole steel cored aluminum strand (aluminum and steel), and low frequency flaw detection to detect the residual cross-sectional area of the steel cored wire, low frequency flaw detection can be used to detect the residual cross-sectional area of steel core wire, the residual cross-sectional area of
aluminum strand is the result of high frequency flaw detection minus the result of low frequency flaw detection.

3.2 Evaluation method of residual tensile force

It is necessary to infer the residual tensile force from the eddy current flaw detection by referring to the data of three databases.

Database A: The relationship between the residual sectional area of steel and aluminum and the output of high and low frequency flaw detection.

Database B: Through the residual cross-sectional area of database a, the database of residual tensile force is derived. Through Cass test, the aluminum single wire samples with reduced cross section are made, and the database of the relationship between cross section and tensile force is made through tensile test.

Database C: Overall pulling force of conductor. The breaking force of the new conductor can be calculated by multiplying the sum of the single line breaking force by 0.9, however, when the conductor corrosion occurs, if the influence of the reduction of the elongation of the aluminum strand is not considered, there will be some errors between the calculated value and the actual value. Therefore, this database is built for the correction of the test value of the manual corrosion conductor and the calculated value of the tension test of the actual running conductor. The flow chart is shown in Figure 5 below:

![Flow chart](image)

Figure 5. Database flow chart

4. Conclusion

In this paper, a kind of corrosion detection technology of power wire based on eddy current detection is proposed, which can provide technical support for judging the corrosion degree and service life of wire. It is of great significance to ensure the safe and stable operation of overhead transmission lines.

Fund project

Science and technology project of State Grid: Research on Development and Application Technology of Anticorrosive Conductor (2018YF-29)

References

[1] AN, N. (2014) Study on Conductor Corrosion and Protection of Transmission Line in Atmospheric Environment. North China Electric Power University, BeiJing.
[2] LI, B., MENG, X.B., WANG, G.L. (2018) Investigation and Analysis on the Corrosion of Overhead Conduction in the South Coastal Areas. J. Electric Wire and Cable., 4: 6-9.
[3] ZHOU, S.L., HU, X.L., YUE, Z.W. (2011) Chemical Analysis of Breaking Accident of 220 kV Aluminum Conductor Steel Reinforced Cable. J. Corrosion and Protection., 32(5): 392-394.
[4] HU, Y.W., HUA, J.F., DANG, P. (2017) Anti-corrosion Measurements of Overhead Conductors. J. Electric Wire and Cable., 4: 12-14.
[5] ZHU, Z.X., CHEN, B.A., ZHANG, Q. (2016) Corrosion Analysis and Protection Technology for Overhead Transmission Conductors. J. Electric Power., 49(5): 8-13.
[6] Xu,K.B, Zhou, J.H. (2004) Eddy Current Testing. China Machine Press, BeiJing.
[7] Cecco, V.S., Drunen, G.V. (1986) Advanced Manual for: Eddy Current Test Method. Canadian General Standards Board, Canada.
[8] TIAN, D.C., CHEN, T.Q., ZHANG, X.Y. (2003) Signal Processing Technology of Eddy Current Testing. J. Nondestructive Testing., 29(10) : 599-602