Influence of Radial Water Penetration on OPGW Transmission Properties and the Solution

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Abstract

This paper describes the influence of radial water penetration on fiber optic overhead ground wire (OPGW) transmission performance. It has been found that defect of the stainless steel optical tube is the main reason for causing radial water penetration. Imperfect welding of the stainless steel tape during production leads to the defect of the stainless steel tube. Firstly, this paper describes the eddy current testing, which can be used to detect the defect of the stainless steel optical tube. Then secondly, two radial water penetration tests for OPGW cables, waterlogged- frozen test and optical unit airproof test, have been introduced. Finally, in order to inhibit radial water penetration through the stainless steel tube and optical unit, two types of OPGW cable constructions have been developed. One is OPGW with an aluminum-covered stainless steel tube. The other is to use a composite tube construction. Since 2000, over 10,000 kilometers of the composite tube construction OPGW cables have been successfully operated under different environments.

Keywords: Wire; cable; optical fiber; water; penetration; optic overhead ground wire (OPGW); stainless steel tube; eddy current

1. Introduction

Recently, an installed OPGW cable from our competitor has been found where some fiber attenuations were increased. Moreover, further study showed that some fibers were broken. After checking the cable sample, we found that there was water in the vicinity of the broken fibers in the middle of cable section. However, we could not find water at both ends of the cable. How can water enter into the cable? Further investigation showed that there were defects in the stainless steel optical tube, as shown in Figure 1.

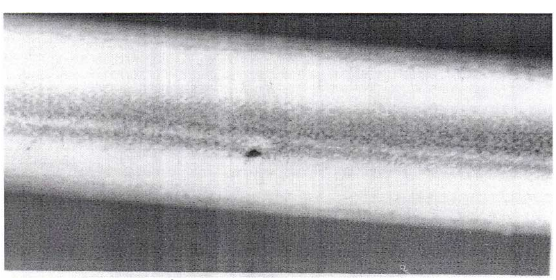

Figure 1. Defect in the stainless steel tube

It became apparent that water transmitted through these defects and seeped into the vicinity of the optical fiber. We call this type of penetration radial water penetration. Water or other fluid can also penetrate into the cable through the ends of the cable and migrate throughout its length. The flow of water or other fluid within the cable core or along the cable sheath interfaces (or inner surface of the stainless steel tube in the case of OPGW) is called longitudinal water penetration. Longitudinal water penetration has been investigated intensively. However, up to now, only a few people have paid attention to radial water penetration. In fact, radial water penetration can also significantly influence OPGW transmission performance. This paper will concentrate on radial water penetration. Firstly, we will describe the eddy current testing, which can be used to detect the defect in the stainless steel optical tube. Then secondly, two radial water penetration tests for OPGW cables will be introduced. Finally, we will suggest two types of OPGW cable constructions to prohibit radial water penetration.

2. Water Penetration

2.1 Longitudinal Water Penetration

OPGW cables with the stainless steel tube are widely used at present. The optical fibers are loosely housed inside the tube. A filling compound fills the tube around the optical fibers, preventing water or moisture from entering and allowing the optical fiber to "float" within the buffer tube. The filling compound can eliminate the possibility of the longitudinal penetration and flow of water within the cable core or along the inner surface of the stainless steel tube.

The longitudinal water penetration test for cables shall be conducted in accordance with the requirements of EIA/TIA-455-82B [1]. Figure 2 shows a typical longitudinal water penetration test set-up.

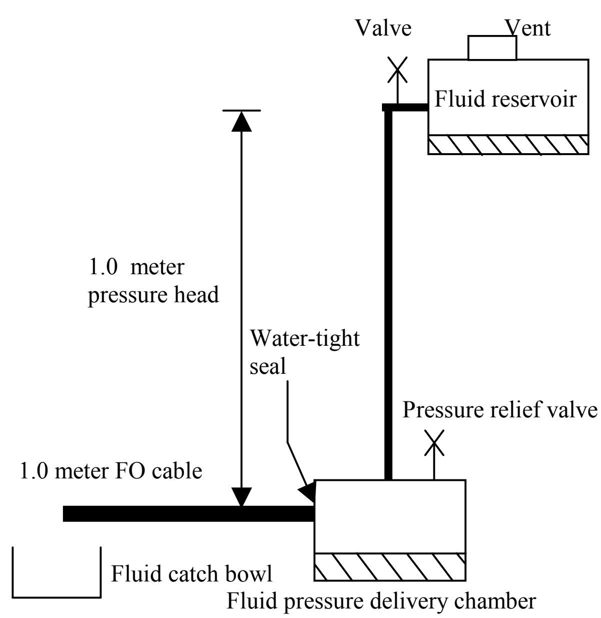

Figure 2. Longitudinal water penetration test set-up

No water shall leak through the open end of the 1 m sample. If the first sample fails, one additional 1 m sample, taken from a section of cable adjacent to the first sample, may be tested for acceptance.

2.2 Radial Water Penetration

If there are defects in the stainless steel optical tube of the OPGW, water or other fluid can penetrate into the stainless steel tube and freeze in the vicinity of the optical fiber. This could lead to an increase in attenuation or fiber breakage. We call this type of penetration radial water penetration. Defects in the stainless steel optical tube are the main reason for causing radial water penetration in the OPGW. Radial water penetration can significantly influence OPGW transmission performance.

Imperfect welding of the steel tape during production leads to the defect in the stainless steel tube. It is very important to improve the welding technology to avoid these defects. It is also important to find these defects during production. The eddy current testing [2] can be used to detect the defects in the stainless steel tube.

3. Eddy Current Testing

3.1 Physical Principles of Eddy Current Testing

Figure 3 shows fundamental physical principles of eddy current testing [2]. The current in the excitation coil generates an alternating electromagnetic field in the test piece where it induces an eddy current. The eddy current follows the characteristic of the exciting current, but is in the opposite direction. Eddy currents are formed on the material surface in direct proportion to the excitation frequency. Thus the eddy current penetration depth is reduced with increasing frequency. If the eddy currents coincide with material defects, such as cracks, cavities, surface damage marks, or faulty welded joints, they can not propagate in the preferred direction of flow. This causes a disturbance in the existing magnetic field, and thus a reaction of the test coil arrangement. This phenomenon is used for the identification of material defects.

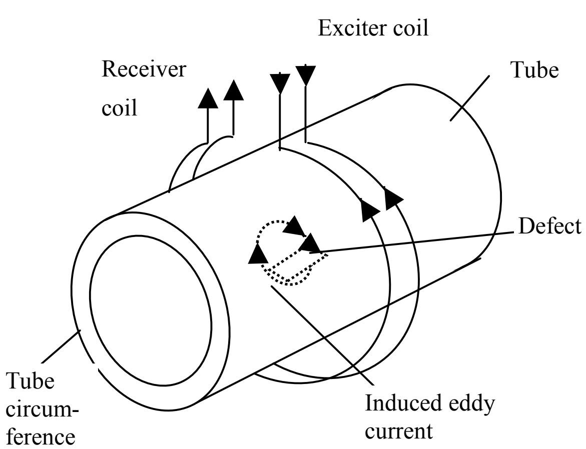

Figure 3. Physical principles of eddy current testing

3.2 Penetration Depth

The most common definition of penetration depth is the depth at which the eddy current density has fallen to a value of 1/e of the value on the test piece surface. The penetration depth is dependent on the test frequency as well as the electrical conductivity and the permeability of the material.

The eddy current penetration depth δ (mm) can be approximately estimated by [2]:

$$\delta = 50.3 \times [\zeta/(f \times \mu_{rel.})]^{1/2} \qquad (1)$$

where ζ is the specific resistance (μΩ cm), $\mu_{rel.}$ is the relative permeability, and f is the test frequency in Hz.

With an increase in frequency, the penetration depth decreases. By choosing test frequency, the detected depth can be adjusted.

The sub-surface eddy currents in a material exhibit a phase difference relative to the surface currents. This effect can be utilized to differentiate between minor surface imperfections, as well as more serious internal material defects. The magnitude of the phase displacement is dependent upon the test frequency. A reduction in the test frequency results in a smaller phase displacement.

4. Radial Water Penetration Test

The test method described in EIA/TIA-455-82B [1] is only for the longitudinal water penetration test, but not suitable for the radial water penetration test. The waterlogged-frozen test and optical unit airproof test [3] can be used to check radial water penetration of the OPGW cables.

4.1 Waterlogged-Frozen Test

At first, a sheave test will be carried out on a sample of OPGW cable approximately 5 m long, according to the method provided by IEEE Std 1138 - 1994 [4]. After the sheave test, the OPGW cable sample will be placed in water for at least one hour. Keen attention should be taken to keep both ends of the cable out of water. The optical attenuation of the cable sample will be measured. Then, the test cable will be placed in a temperature chamber with a temperature of –20 ℃ for at least two hours. The optical attenuation of the test cable will be measured again after two hours. If there are defects in the stainless steel tube, these will become larger after the sheave test. Water can penetrate through these larger defects and enter into the optical unit. At a low temperature of –20 ℃, water in the vicinity of the optical fiber will freeze, and this could lead to an increase in attenuation or fiber breakage. According to the attenuation changes, we can determine whether or not there are defects in the stainless steel optical tube.

4.2 Optical Unit Airproof Test

The fibers and filling compound will be removed from the stainless steel tube. One end of the stainless steel tube will be sealed. Another end will be connected to a nitrogen pump. The pump puts nitrogen into the stainless steel tube until a pressure of 0.3 Mpa is reached. The air pressure shall be maintained for a minimum of two hours. The pressure measurement will be taken after two hours. If there are defects in the stainless steel tube, the measured pressure will be reduced significantly or become zero.

5. Methods for Inhibiting Radial Water Penetration

To prevent radial water penetration through the stainless steel tube and optical unit, two types of OPGW cable designs have been developed as follows:

5.1 OPGW with an Aluminum-Covered Stainless Steel Tube

In this construction, an aluminum layer covers the stainless steel tube [5]. The thickness of aluminum is about 0.8 mm. The aluminum layer can inhibit radial water penetration, even if there are defects in the stainless steel tube.

For the conventional OPGW with a bare stainless steel tube, galvanic corrosion may occur between the stainless steel tube and aluminum-clad steel wires or aluminum alloy wires. This corrosion is due to the different metal’s contact with each other. Grease is used to fill up space between the steel tube and wires to prevent galvanic corrosion. However, there is a possibility that the grease will deteriorate after long-term operation in severe environments. The OPGW with an aluminum-covered stainless steel tube can eliminate galvanic corrosion without the need for grease because its aluminum-covered tube is in contact with aluminum-clad steel or aluminum alloy wires.

5.2 OPGW with a Composite Tube Construction

In this construction, an inner plastic lining tube is put next to the inner surface of the stainless steel tube. Figure 4 shows the composite tube construction.

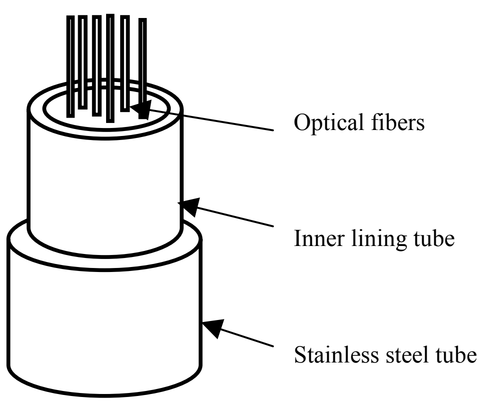

Figure 4. Composite tube construction

The stainless steel tube and inner lining tube form an organic whole with high strength adhesive. The inner lining tube eliminates the effect of radial water penetration by reason of welding defects and separating out the hydrogen by reason of gel non-compatibility with stainless steel.

The inner lining tube can also protect fibers from mechanical damage, such defects as burr, sawtooth formed during laser welding. This type of OPGW cables was developed in 2000. Since then, we have already produced and installed over 10,000 kilometers of OPGW cables with the composite stainless steel loose tube construction.

6. Conclusions

Radial water penetration can significantly influence OPGW transmission performance. A defect in the stainless steel optical tube is the main reason for causing radial water penetration. Imperfect welding of the steel tape during production leads to the defect in the stainless steel tube. It is very important to improve the welding technology to avoid these defects. It is also important to find these defects during production. The eddy current testing can be used to detect the defects in the stainless steel optical tube. By choosing the test frequency, the detected depth can be adjusted. The waterlogged-frozen test and optical unit airproof test can be used to check radial water penetration of OPGW cables. In order to inhibit radial water penetration through the stainless steel tube and optical unit, two types of OPGW cable designs have been developed. One is OPGW with an aluminum-covered stainless steel tube. The aluminum layer can both inhibit radial water penetration and eliminate galvanic corrosion. The other is to use a composite tube construction. In this construction, an inner plastic lining tube is put next to the inner surface of the stainless steel tube. The inner lining tube eliminates effect of radial water penetration by reason of welding defects and the separating out the hydrogen by reason of gel non-compatibility with stainless steel. Since 2000, over 10,000 kilometers of the composite tube OPGW cables have been successfully operated under different environmental conditions.

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8. References

[1] EIA/TIA-455-82B, “Fluid Penetration Test for Fluid-Blocked Fiber Optic Cable,” (February, 1992)

[2] Operating Manual, EDDYCHEK LAB 2, pp. 1-13

[3] Test Methods for Fiber Optic Overhead Ground Wire, JCS7501 (2001)

[4] IEEE Std 1138-1994, “IEEE Standard Construction of Composite Fiber Optic Overhead Ground Wire (OPGW) for Use on Electric Utility Power Lines,” Annex D, Sheave Test, pp. 29-30 (1994)

[5] T. Tsuji, Y. Namekawa, T. Fukasawa and S. Momomoto, “New OPGW with Aluminum-covered Stainless Steel Tube,” Hitachi Cable Review, No. 20, pp. 73-78, (August, 2001)

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