Regular Paper
J. Korean Inst. Electr. Electron. Mater. Eng.
Vol. 28, No. 10, pp. 670-675 October 2015
DOI: http://dx.doi.org/10.4313/JKEM.2015.28.10.670
ISSN 1226-7945 (Print), 2288-3258 (Online)

가공 배전선로 진단시스템을 위한 최적 센서 개발

이경섭[a]
서일대학교 전기과

Development of Optimal Sensor for Diagnostic System in Overhead Distribution Power Lines

Kyeong-Seob Lee[a]
Department of Electrical Engineering, Seoil University, Seoul 131-702, Korea

(Received August 20, 2015; Revised September 14, 2015; Accepted September 17, 2015)

Abstract: Degradation diagnosis of cable is one of major issues for operation and maintenance in overhead distribution power lines. The diagnostic system for overhead power lines is composed of three parts in functional aspect - a travelling unit, a sensing unit and a communication unit. Among them, sensor detects the defects such as corrosion and disconnecting of power lines. Performance of sensor is very important, and besides, the size and structure of sensor is restricted for installation to small and lightweight diagnostic system. This paper suggests an optimal eddy current sensor best suit for small and lightweight diagnostic system in consideration of detecting performance, size and ease of installation and so on. Proposed sensor has been designed by Drum core structure and can be applied to the all domestic overhead power lines regardless of the cross-sectional areas. Also, it is showed that results of mock environmental test are satisfied.

Keywords: Eddy current sensor, Diagnostic system, Degradation, Corrosion, Overhead power lines

1. Introduction

Distribution power lines are most closely installed to customers by nature and faced with the various potential accidents such as degradation of apparatus, natural disasters and contacts with the extraneous objects. Of these various cases of accidents, ones caused by the degradation of apparatus accounted for about 11% of the total in the year 2006 [1]. These accidents from degradation are known as disconnection by means of water penetration. At the time of such accidents, these cases can entail casualties as well as enormous financial loss, therefore a reliable device for diagnosing the corrosion of distribution power lines by degradation or disconnection is very much needed.

The diagnostic system for detecting corrosion or disconnection of overhead power lines can be divided as follows: travelling module for moving along power lines, communication module for communicating between the system and remote users, sensor module for diagnosis of lines. Of these, the sensor is most closely associated with the reliability of detection. Therefore, development of the sensor suitable for the diagnostic

a. Corresponding author; 20120008@seoil.ac.kr

system is most important.

The NDT (non destructive test) methods for detecting defects such as degradation or disconnection of overhead distribution power lines have X-ray radiography, infrared detection testing and eddy current testing, etc. The X-ray radiography has a problem that the device is huge and the usage of radiation is restricted. The infrared detection testing also has a problem in that temperature conditions affect the accuracy of detection. So the eddy current testing is widely used for diagnostic facilities.

The OC Runner developed by Tohoku Electric Power of Japan increased reliability of detection by applying SQUID (superconducting quantum interference device) eddy current sensor, but left the maintenance difficulty of cryostat and replacement of helium gas due to the character of the superconductive sensor. Plus, if it were to be introduced to Korea, the qualification for the application possibility would be needed as the capacity and installation layout of wire are different here [2].

The ACSR life assessment system developed by KEPRI (Korea Electric Power Research Institute) is an application of eddy current sensor in a solenoid type, but due to its 26[kg] weight, it is difficult to use. It also can cause measurement errors as self impedance of contact surfaces can happen when the two coils are contacted, creating a flaw in terms of reliability of measurement [3].

It is convenient to use a small and lightweight diagnostic system, but, the size and structure of sensor module is restricted by the diagnostic system. Therefore, development of eddy current sensor suitable for small and lightweight diagnostic system is required [4].

In this paper, York core type sensor (Type 1, 2) and Drum core type sensor (Type 3) that can be applied for the diagnostic system of overhead distribution power lines are designed. The testing performance and installation requirements for each sensor are comprehensively compared.

Developed eddy current sensor is most suitable for small and lightweight diagnostic system ranging around 5[kg], and can be applied to both 95 and 160[㎟] of overhead power lines.

2. Eddy Current Sensor

2.1 Requirement for the sensor

The overall size and weight of the overhead power line diagnostic system is most influenced by the size and weight of the travelling mechanism. Consequently, the reduction in size and weight of the diagnostic system is restricted. And it means that the structure, size and layout of the sensor module are influenced by the structure or size of travelling apparatus.

The overhead lines are located at a certain height from the ground buttressed by electric poles. If diagnostic system is too big or heavy, it is very difficult and dangerous for diagnosis of power lines. So a small and lightweight diagnostic system is needed. Several factors should be considered for designing of sensor which is to be applied for a small diagnostic system, and they are as follows:

- The detection performance of the sensor should be assured.
- The sensor, sensor controller, ease of installation and layout of each modules should be suitable for the size and structure of travelling module.
- The vibration of the diagnostic system by the wind or tension of the cable can cause changes the distance between the sensor and the cable. Therefore, adequate distance for diagnosis should be assured.
- The sensor design should reflect the characteristics of the distribution lines using different thickness cables according to the location of lines and the load conditions connected with lines.
- Low-power sensor should be adopted.

2.2 Type 1 sensor

Type 1 sensor is designed in York core structure primarily considering the ease of installation for the actual travelling apparatus. York Type Core has the advantage of making up the difference from the change of the parent material and minimizing the change of the distance at the time of diagnosis. The structure of the general York core sensor is showed in Fig. 1.

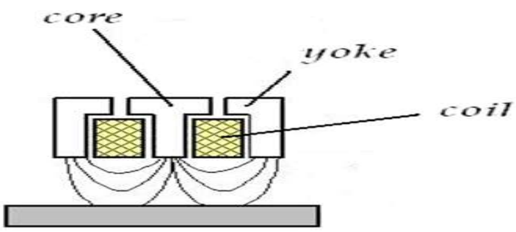


Fig. 1. Structure of York sensor.

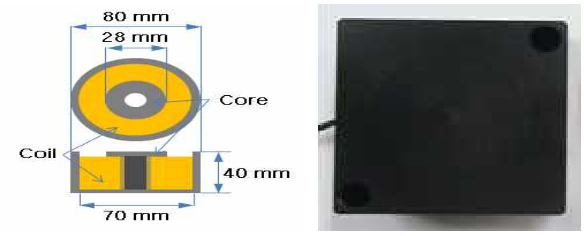


Fig. 3. Type 2 sensor.

The core of Type 1 sensor is selected the ferrite material having high magnetic permeability. The maximum measurement range is 10[mm] based on the characteristic that the larger the diameter of sensor core is the longer the measurement range is. In order to be applied for all the cables which have different thickness, the sensor controller is designed to make the input-output frequency variable when the thickness of the parent material change and it is molded by epoxy. In order to enhance the accuracy for detecting, low pass filter and amplifier are applied. For remote transmission, transmit-reception function is built in sensor controller. The Type 1 sensor is shown in Fig. 2.

2.3 Type 2 sensor

Type 2 sensor for corrosion detecting is designed in York core structure the same as Type 1 sensor. The radius of the sensor is enlarged to increase the lift-off which is a shortcoming of Type 1 sensor. To prevent increased sensor bulk due to the increase of lift-off, the number of coil turns is reduced to 20% of Type 1 sensor. To reduce the noise streaming into the rear end of sensor, it is molded by epoxy securing distance in the rear end of sensor.

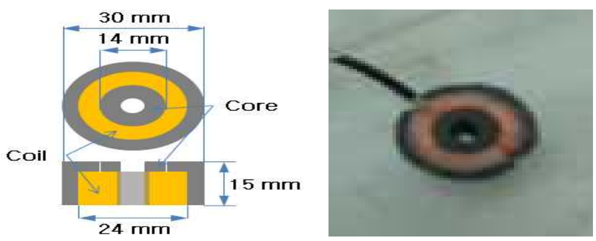


Fig. 2. Type 1 sensor.

The amplifier of measurement signals, low pass filter, DSP (digital signal processing) is applied in sensor controller. For remote transmission, transmit-reception function is built in controller. Type 2 sensor is shown in Fig. 3.

2.4 Type 3 sensor

Type 3 sensor for corrosion detecting is an alteration from York core structure of Type 1, 2 sensors to Drum core structure to make its easy installation into the diagnostic system. To reduce the size of the sensor, the lift-off is shortened compared to Type 2 sensor. The number of coil turns is also adjusted as the detection performance does not vary with a change of coil turns, and it is molded by epoxy. Lock-in Amplifier is applied in the sensor controller to prevent the original signal from disappearing as a result of noise at the time of detecting very small signals derived from the eddy current.

The multiple-channel DSP which can handle four signals simultaneously and transmit-reception function is built in sensor controller. The Type 3 sensor is shown in Fig. 4.

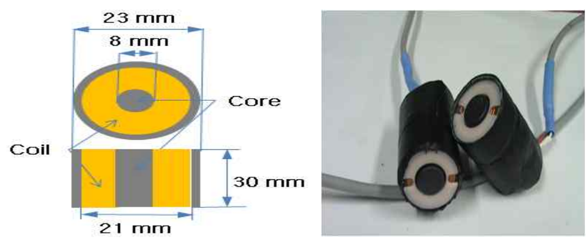


Fig. 4. Type 3 sensor.

2.5 Comparison of the sensors

All of the sensors are tested 10 times for verification of detection performance onto 95[㎟] cable in test conditions shown in Fig. 5. Detailed explanation of test conditions are described below. Average values of test results are shown in table 1. As the results in table 1, detection performance of all sensors is satisfied. The features of each sensor are follows.

Type 1 sensor is easily installed to the diagnostic system, and disconnection can be detected comparatively accurately. If the distance between the sensor and the cable is increased, it is difficult to distinguish each wire and to detect disconnection and partial break of wires in stranded cable. If the lift-off is increased, the size is increased accordingly, so it is not suitable for small and lightweight diagnostic system.

Type 2 sensor has very high detection performance by increasing the lift-off, the size created by the increased lift-off is too big to be installed into the system. If the size gets smaller, the detection performance drops sharply, so it is not suitable for diagnostic system.

Type 3 sensor has secured enough lift-off and detection performance by applying Drum core. So, diagnosis of overall wires is possible and also easy for installation as the size is small.

By comprehensive comparison of such factors in each sensor as detection performance, size and installation convenience, Type 3 sensor is most suitable for small and lightweight diagnostic system. The comparative results for each sensor are shown in Table 2.

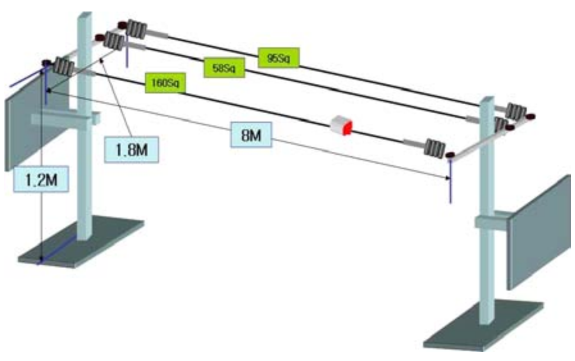


Fig. 5. Test conditions for sensors.

Table 1. Test results of sensors.

Cable	Corrosion time	Detection Value(Avg.)		
		Type 1	Type 2	Type 3
95 [㎟]	0	2,197	2,237	2,220
	18	2,208	2,368	2,339
	24	2,223	2,401	2,365
	27	2,239	2,445	2,387

Table 2. Comparison results of sensors.

	Type 1	Type 2	Type 3
Type	York core	York core	Drum core
Lift-off (mm)	5	16	13
Size (mm)	30 Φ×15	80×80×40	23 Φ×30
Detecting mode	Disconnecting	Corrosion	Corrosion
Feature	· Concentration of magnetic field by core	· Enough depth of penetration	· Detecting overall wire by small diffusion
Freq. (kHz)	243	95.23	119.2
Remarks	· Shallow depth of penetration · Errors between wires	· Big size · Difficulty of installation	· Complexity of sensor controller

3. Test and results

As a means of differentiating normal wires from corroded wires, artificial corrosion by depositing sodium hydroxide is created before measuring the eddy current sensor for evaluation [5,6].

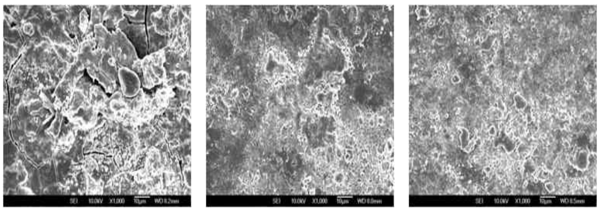
The performance evaluation of Type 3 sensor was conducted in the test conditions of Fig. 5 and it is designed similarly to the real conditions. For the 95[㎟] and 160[㎟] insulation cables installed into the mock environment, each zone was corroded for 18, 24, 27 hours.

The cable by each corroding time zone and the surfaces of the cable taken by a SEM (scanning electron microscope) is shown in Fig. 6 and Fig. 7. The changes of the cable diameter by the corroding time zones are shown in Table 3.

As the results in table 3, the diameter change of wire due to corrosion is reduced by more than 10[%] for 18 hours or more.

18[hour] 24[hour] 27[hour]

Fig. 6. Cable by corrosion time.



18[hour] 24[hour] 27[hour]

Fig. 7. SEM photo by corrosion time.

Table 3. Results of samples by corrosion time.

Corrosion time [hour]	Diameter[mm]				Corrosion rate[%]			
	Front	Middle	Rear	Avg.	Front	Middle	Rear	Avg.
0	12	12	12	12	0	0	0	0
18	11	10.4	11	10.8	8.3	13.3	8.3	10.0
24	9.9	9.2	10	9.7	17.5	23.3	16.7	19.2
27	9.4	8.8	9.7	9.3	21.7	26.7	19.2	22.5

3.1 Test results

After the Type 3 sensor(Drum core structure) is installed into the diagnostic system, performance tests are carried out more than 100 times repeatedly for 95 [㎟] and 160[㎟] cable. The test results for 95[㎟] and 160[㎟] cable are shown in Table 4.

Table 4. Detection value of sensor by artificial degradation.

Cable	Detection value	Corrosion time[hour]			
		0	18	24	27
95 [㎟]	Avg.	2,222	2,334	2,360	2,393
	Max.	2,230	2,367	2,401	2,420
	Min,	2,155	2,248	2,321	2,372
	Dev.	38.4	47.8	56.3	33.1
160 [㎟]	Avg.	2,341	2,421	2,441	2,479
	Max.	2,375	2,451	2,480	2,510
	Min,	2,355	2,383	2,401	2,373
	Dev.	24.2	35.6	28.2	31.2

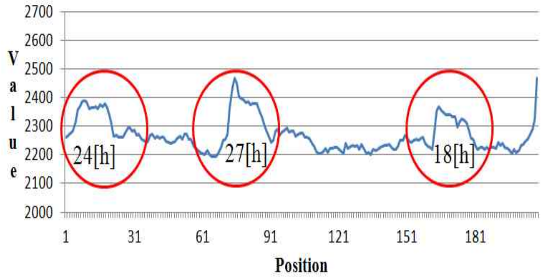


Fig. 8. Waveform of test result for 95[㎟] cable

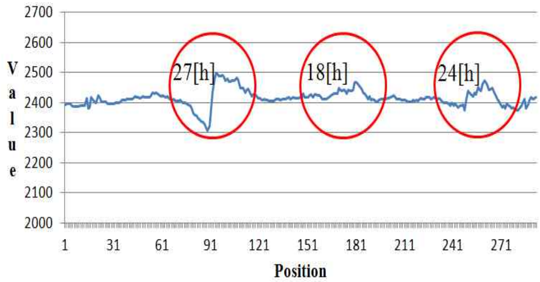


Fig. 9. Waveform of test result for 160[㎟] cable.

The waveform of test results by average value is shown in Fig. 8 and Fig. 9 respectively. As the results in table 4, it is sure that the measurement value of eddy current sensor is increased as corrosion time goes by.

4. Conclusions

This paper compares core structure to another sensor using a different detection methodology to develop an eddy current sensor for diagnosing degradation of the overhead distribution power lines.

The sensor is designed by utilizing York core structure and Drum core structure. The detection performance, size and convenience of installation are comprehensively compared. As the comparison result, Drum core sensor is most suitable sensor for the small and lightweight diagnostic system.

It is showed that the performance tests of proposed sensor for 95[㎟] and 160[㎟] cable are satisfied. It is confirmed that the value of eddy current sensor is increased as corrosion processes. It is verified that proposed sensor can be detected the cables which have more than 10% degradation in progress regardless of the thickness of the cables.

REFERENCES

[1] C. H. Kim, T. Y. Kim, Y. C. Oh, W. S. Choi, and C. N. Jo, *J. Korean Inst. Electr. Electron. Mater. Eng.,* **27**, 322 (2014).

[2] T. Nonaka, H. Yoshimi, F. Sato, H. Matsuki, and T. Sato, *IEEE Trans. on Magnetics*, **38**, 3321 (2002). [DOI: http://dx.doi.org/10.1109/TMAG.2002.802303]

[3] Y. W. Kang, J. W. Kang, B. M. Yang, and J. K. Jeong, *J. Korean Inst. Illuminating and Electrical Insulation Eng.*, **12**, 12 (1998).

[4] Y. C. Oh, T. Y. Kim, K. S. Lee, H. S. Jeong, J. S. Yoo, J. K. Yang, J. B. Lee, K. H. Lee, and C. H. Kim, *Proc. of KIEE Summer Conference* 2140 (2009).

[5] Korean Standards, *KS D ISO11463* (2013).

[6] Korean Standards, *KS D ISO11474* (2013).

[7] Y. M Cheong, *J. Korean Soc. Nondestructive Testing*, **13**, 94 (1993).

[8] K. J. Kim, Y. C. Oh, K. S. Lee, H. S. Jung, T. Y. Kim, M. H. Choi, M. Y. Song, C. G. Shin, and J. S. Kim, *J. Korean Inst. Electr. Electron. Mater. Eng.,* **24**, 166 (2011).