The Condition Assessment of Cast Resin Molded Transformer Windings Using Vertical Analysis of Thermal Distribution

Young-Bae Lim†, Jong-Wook Jung*, Jin-Soo Jung*, Seong won Cho** and Joon-Bum Kim**

Abstract - This paper presents an assessment method in integrity of the windings in cast resin molded transformers by using vertical analysis of thermal distribution. The proposed method is to compare the temperature distribution in a sound specimen with that in the faulted specimen with a layer to layer short circuit. Temperature distribution was acquired by an infrared thermography system, and the Arrhenius equation was adopted to the accelerated test. The proposed method can be used to detect the failures in the transformers.

Keywords: vertical thermal distribution, cast resin molded transformer, Arrhenius equation, infrared thermography

1. Introduction

Essential power facilities have recently been moved underground because of an increase in population of city and dislike of electrical equipments. This is one of the reasons why cast resin molded transformers were employed at the places with special conditions such as underground. The transformers have relatively high performance in thermal resistance even under a fire and condition insulating property, while they are very weak to various surges.

Unfortunately, insulation diagnosis is not easy due to the transformer's excellent insulating performance. Therefore, the degradation of the transformer insulation cannot be easily detected by the conventional diagnostic techniques, and there are not proper diagnostic techniques to assess the insulating condition under energized condition at the present state.

Using an infrared thermal imager to the diagnosis of power equipments has continuously increased with the advent of the first commercial IR thermal imager in the 1960's, the development of focal plane array detecting devices in the 1980's, and the advent of uncooled microbolometric detectors in the 1990's[1, 2].

The thermal imager is frequently used to detect the defects in power apparatuses accompanying temperature rise with occurrence of defects because of its remote data acquisition performance. In particular, the IR thermal imager is often used when it is difficult to detect the failure condition by using the electrical method or when any equipment needs the diagnosis under energized condition.

The imager is presently only used for the detection of local heat generated by loose terminals or contact, but thermography techniques are not enough to assess the condition of the power equipments quantitatively.

In this paper, the infrared thermal imager was used for the diagnosis under energized condition of the transformer specimens acquired by accelerated aging test applying Arrhenius equation, and the dielectric dissipation factor (tanδ) as a reference was compared with the results.

2. Experiment

2.1 Preparation of Specimens

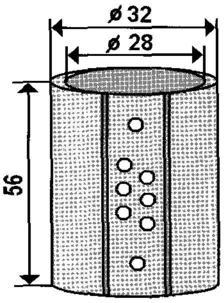

Fig. 1 Appearance and dimension of specimen

Cast resin molded transformers show stable insulating property. Because their windings are structurally separated the insulation between the windings is hardly deteriorated. Therefore, the considerations for the degradation can be limited to the deterioration between layers. The probability

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of failure events at the 2nd winding is relatively low because the coil size of the 2nd winding is large and the operating voltage is low.

Therefore, only the 1st winding was used as a specimen for the experiment. The specimen shown in Fig. 1 is the high voltage winding of the transformer for 22.9kV with 3,922-turn, and its coil was 0.85mm in diameter.

2.2 Experiment

The Arrhenius equation was introduced into the accelerated test. Related expression for the accelerated aging temperature and the aging time can be written as;

$$T_R = \frac{b}{\ln\left(\frac{L_R}{L_A}\right) + \frac{b}{T_A}} \quad (1)$$

Where, T_R is the temperature limit in degrees Kelvin, 428K, T_A is a setting temperature for the accelerated test in degrees Kelvin, and b is the constant related to the time-to-failure temperature relationship depending on the insulation system involved and representing the slope of the Arrhenius plot, 2.2×10^4. L_R and L_A implies the lifetime(4×10^4 hours) at the temperature limit(T_R) and the average value of time-to-failure at test temperature(T_A), respectively[3].

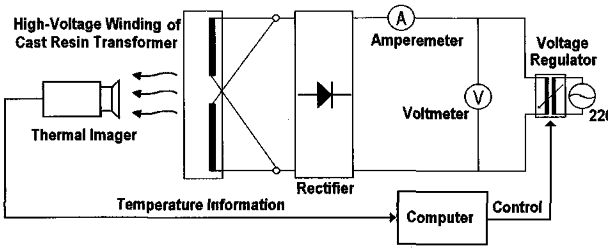


Fig. 2 Schematic of aging test system

Fig. 2 shows the accelerated aging test system. The load current and temperature of the hottest spot can be controlled and monitored by the computer and the thermal imager in real time. The temperature of the winding was controlled by the load current limit. The direct current rectified by a bridge rectifier was used to reduce the current limited by the inductance of the winding, 2.7H. In order constantly to keep the temperature of the winding, the current for aging was controlled by the computer. The hottest spot of the winding can be automatically tracked by the computer connected to an IEEE1394 port of the thermal imager.

The IR thermal imager is the TVS-8502 of Nippon Avionics Co., Ltd. The temperature resolution of the imager is 0.025°C and the temperature data were analyzed by the computer and the self-made analysis program

The program shown in Fig. 3 was made for the differential analysis on the surface temperature of the specimens under sound condition and failure condition.

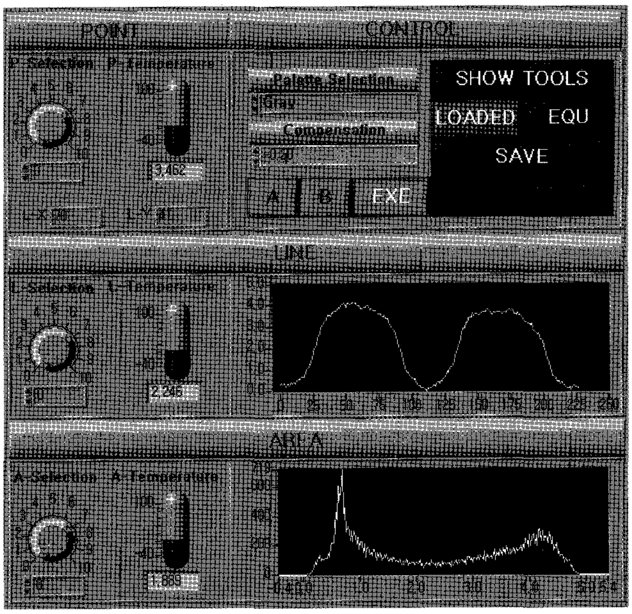


Fig. 3 Analysis program

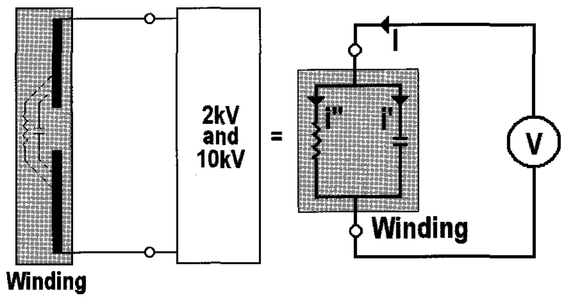
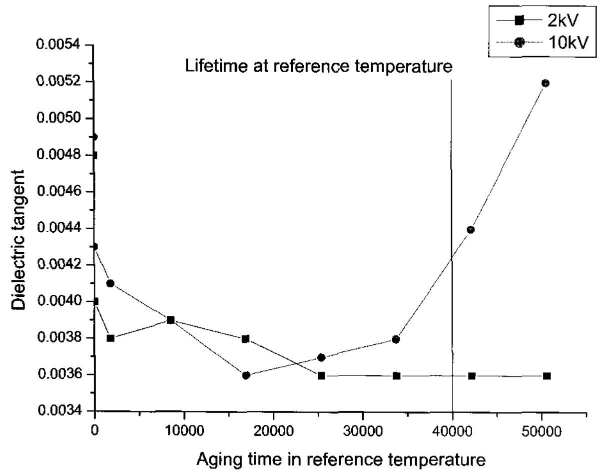


Fig. 4 Circuit for measuring dielectric dissipation factor

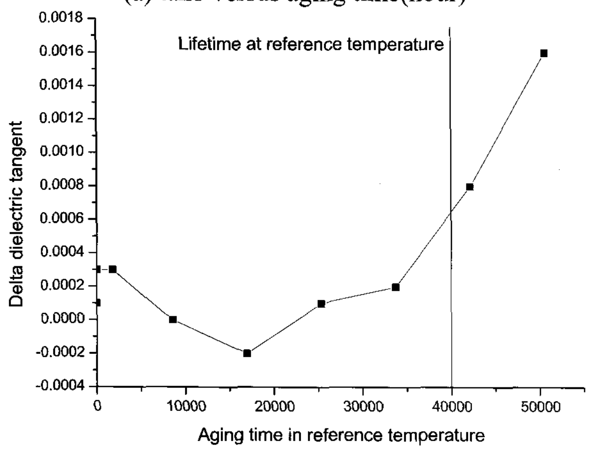
To monitor aging level of the transformer specimens, dielectric dissipation factor was measured by the circuit shown in Fig. 4. The equipment to measure dielectric dissipation is the 2818/5283 made by Tettex Instruments. Then, it was measured after cooling enough to room temperature and taps were separated from the winding specimens to acquire exact dielectric properties.

3. Results and Discussion

The dielectric dissipation factor to assess aging level was measured at each aging step. There was no remarkable increase in tanδ when comparing the result shown in Fig. 5 with initial state. With aging time, however, tanδ slowly decreased to 0.0036 and then abruptly increased. The tanδ increased at 40,000 hours in the view of reference time, and layer-to-layer short circuit occurred in the specimens after 45,000 hours.



(a) tanδ versus aging time(hour)



(b) Difference between 10kV and 2kV dielectric dissipation vs, aging time(hour)

Fig. 5 Measured dielectric dissipation

40% of full load current rating was applied to the failure specimen acquired by the accelerated thermal test and the sound specimen. The results are shown in Fig. 6 and Fig. 7.

Fig. 6 shows the thermal image and the temperature on the vertical line of the image in the initial state of the high voltage winding. The vertical and the horizontal axis are the temperature on the line of the image in degree Celsius and vertical pixel position from top to bottom the line on the thermal image, respectively. The thermal difference between the hottest spot and the coldest spot was about 2°C. The difference was due to the structural arrangements of the coil sections. The thermal difference between the upper half and the lower half was about 1°C. The difference was considered because of the convection of heat.

Fig. 7 shows the thermal image and the temperature on the vertical pixel position of the image of the failure specimen and the increased surface temperature of the specimen. The phenomenon is caused by the Joule's heat rise due to the increase in conduction current.

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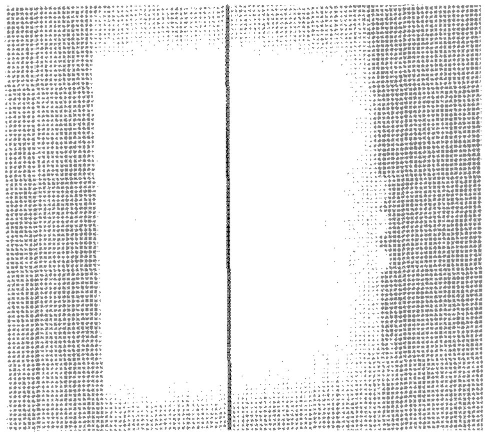
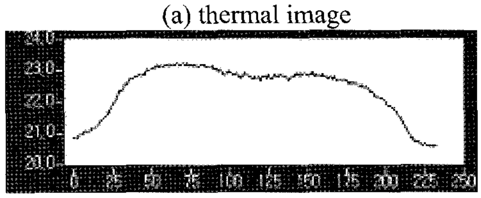
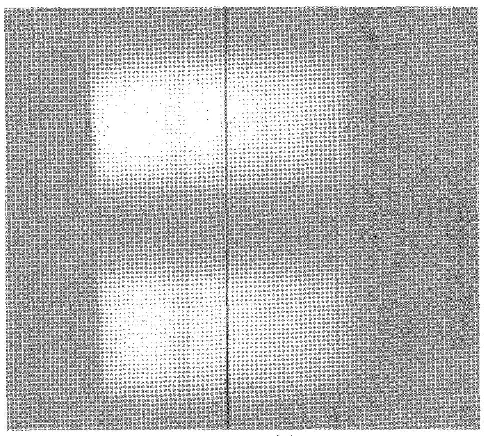


(a) thermal image

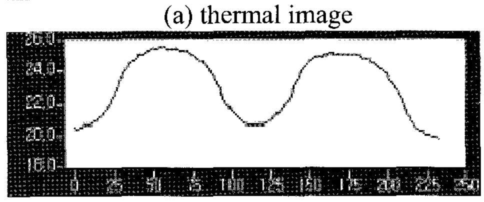


(b) temperature curve

Fig. 6 Vertical distribution of temperature of the sound specimen

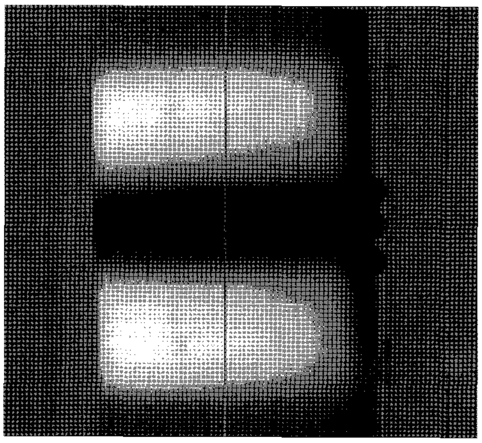


(a) thermal image

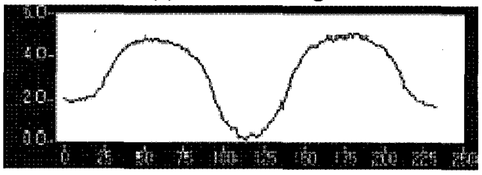


(b) temperature curve

Fig. 7 Vertical distribution of temperature of the failure specimen

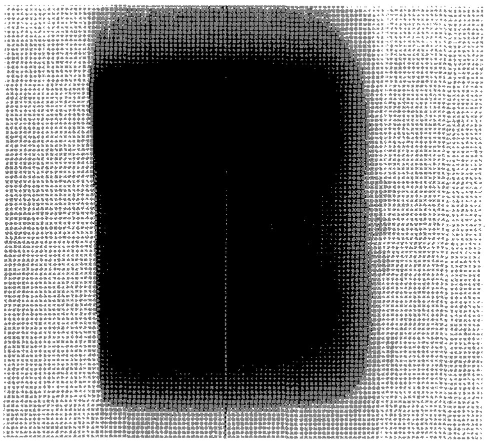


(a) thermal image

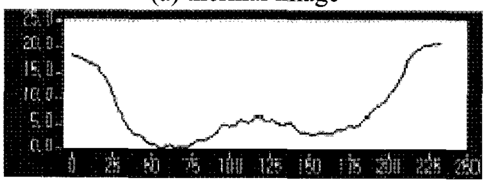


(b) temperature curve

Fig. 8 Vertical thermal distribution of the differential image between the sound specimens and the failure ones



(a) thermal image



(b) temperature curve

Fig. 9 Vertical thermal distribution in the differential image between 40% and 80% conditions of the full load current rating

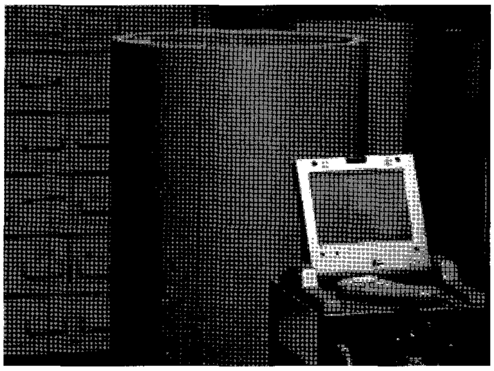


Fig. 10 The picture on the spot

4. Conclusions

The thermal distribution between the sound specimen and the failure one shows different aspect. In particular, the differential analysis of the results using the self-made program presents the probability of the qualitative analysis directly by intuition. When using the method presented in this paper, the visual results can be acquired by the alteration of the dielectric dissipation between the sound specimen and the failure one was not plenty.

Thus, practical use of this diagnosis method will be able to find out the failure symptom with ease in cast resin molded transformer.

Acknowledgement

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References

[1] Xavier P. V., "Nondestructive testing handbook volume 3 infrared and thermal testing," American society for nondestructive testing, Inc., pp. 21-22, 2001.

[2] Peter C. and C. T. Elliott, "Infrared detectors and emitters: materials and devices," Kluwer academic publishers, pp. 1-4, 2001.

[3] IEEE standard C57.12.60, "Solid-cast and resin-encapsulated power and distribution transformers," pp. 2-4, 1998.

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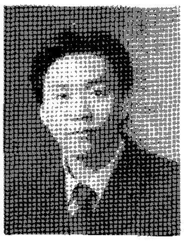

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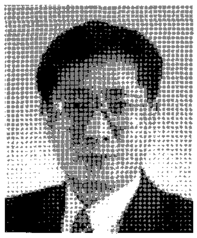

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