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Diagnostic Technique for Cast Resin Molded Transformer Windings Using Active Thermography

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

Abstract - Temperature distribution measured to estimate the condition of an electrical apparatus is an absolute reference for the apparatus conditions and the difference between the reference temperature and the current temperature. Because of passive thermography, without the external thermal stimulation, the difference in surface temperature between the region of interest and back ground shows that the results can apply only to the estimation or the monitoring for the condition of loose terminal and the overload pertaining to the rise in temperature. However, a thermal diffusion in the active thermography is differently generated by the structure and condition of the surface and subsurface. This paper presents a nondestructive test using this behavior and deals with the results by heat injection and cooling to the apparatus. The buried discontinuity of subsurface could be detected by these techniques.

Keywords: Active thermography, Cast resin molded transformer, Infrared thermography, Nondestructive testing, Thermal image

1. Introduction

All materials radiate infrared energy. At absolute zero, all energy content, radiation and particle motion cease to exist. It has been physically impossible to create the temperature of absolute zero [1]. In this theory, an infrared thermal imager was developed and has been used to diagnose electrical apparatuses.

An aspect of temperature distribution measured by the infrared thermal imager is an absolute value to the condition of the apparatus [2]. Passive thermography, without the external thermal stimulation, shows the difference in surface temperature between the region of interest and the background. Therefore, the results are used in estimation or monitoring for the condition of loose terminal and the overload pertaining to the rise in temperature.

However, structures needing to be insulated in electrical apparatuses may have the defect in that they do not radiate heat. Molded transformers can also have the defect of not being detected by the passive thermography. Especially, the ground space needed to install power facilities is insufficient because of urbanization and the rapid population growth in the city. Many facilities have recently been moved underground, and the employment of molded transformers due to relative stability against fire has been increased at those places.

Therefore, this paper introduces an active thermography, which measures variation of temperature with time after thermal disturbance, to detect the defects of surface and subsurface. The thermal wave of the active thermography generates the transitional or the perpetual variation of the measurable temperature. As a result, the defect information of surface or subsurface can be estimated by analyzing the variation in temperature after the thermal perturbation.

2. Experiment

2.1 Experiment Outline

Active thermography is a method detecting defects of surface or subsurface by analyzing the variation in surface temperature that appears by reflection and velocity variation of thermal wave after the thermal perturbation.

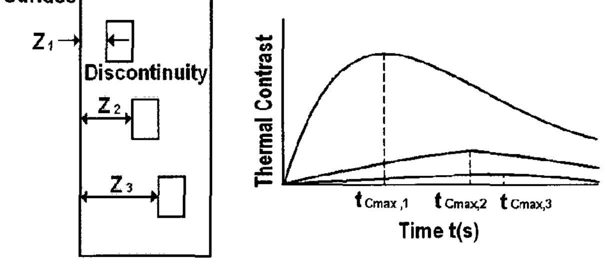

Fig. 1. Thermal contrast as function of subsurface discontinuity depth [3].

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Fig. 1 shows the thermal contrasts under sample surface that appear on the surface by discontinuities (Z_1, Z_2, Z_3) following a brief initial thermal perturbation. It is noticed that the occurrence of the time of maximum thermal contrast t_{Cmax} is proportional to the square of the depth of homogeneous materials. Consequently deeper discontinuities will experience longer t_{Cmax}. The thermal contrast $t_{Cmax,1}$, $t_{Cmax,2}$ and $t_{Cmax,3}$ are the times appeared for the discontinuity Z_1, Z_2 and Z_3 respectively. Thermal contrast C(i,j,t) is computed at time t for a given pixel (i,j) from thermal image T:

$$C(i,j,t)=\frac{T(i,j,t)-T(i,j,t=0)}{T_{soa}(t)-T_{soa}(t=0)} \tag{1}$$

where, T_{soa} corresponds to the surface temperature over a sound area of the thermal image. The image before heating (at t=0) is also subtracted to remove spurious thermal reflections [3-4].

The thermal signal obtained with the active thermography (Fig. 2) is a series of N 2-dimensional thermal images collected with a rate $(\Delta t)^{-1}$, where Δt is the time interval between two sequential thermal images. If each image has L×M pixels, the result of an observation is a three-dimensional array of thermal response values having a dimension of L×M×N. As time evolution functions for a particular pixel with coordinates (i,j), thermal images can be analyzed.

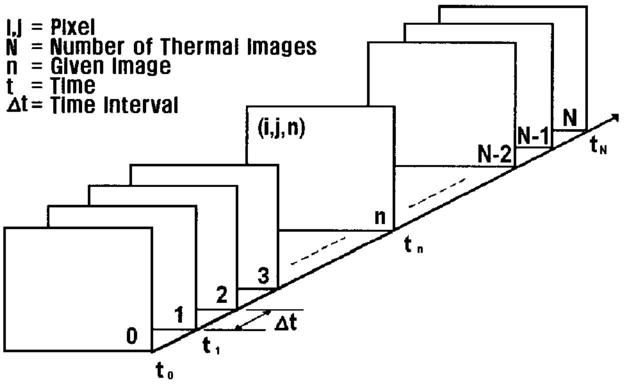


Fig. 2. Series of N thermal images with L×M pixels

2.2 Experiment

In active thermography, the heat injection and the cooling method for thermal perturbation should not accelerate deterioration of test specimens and should be suitable for instant heat perturbation.

Therefore, in this study, 2 lights with 4 halogen lamps (500W) are applied to heat injection because this method can instantly control heat energy on the surface of the specimen (Fig. 3).

The cooling method used compressed air with peak pressure of 8kPa (Fig. 4). Because the air compresses at room temperature, the air will not accelerate the deterioration of the specimen.

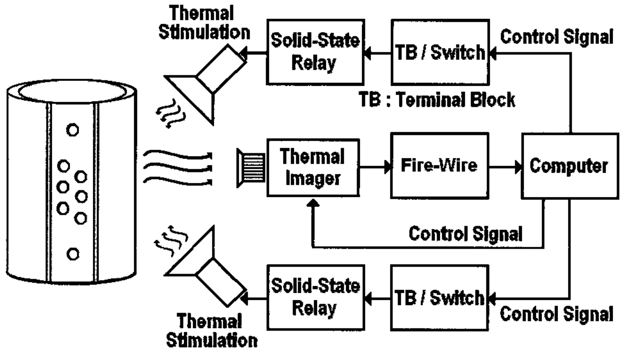


Fig. 3. System block diagram for thermal injection method.

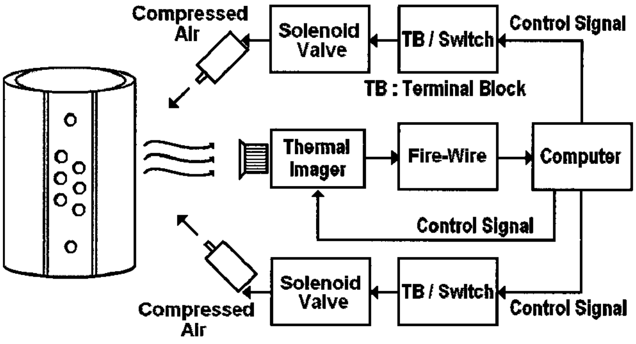


Fig. 4. System block diagram for cooling method.

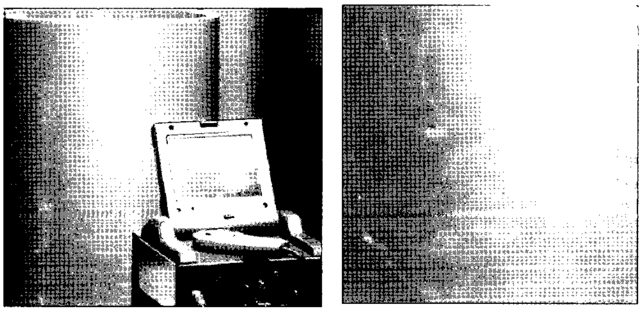

(a) Test equipment (b) Test specimen

Fig. 5. Test equipment and specimen.

The infrared thermal imager (Fig. 5) used in this experiment is the Avionics' TVS-8502, whose temperature resolution is ±0.025℃. The number of available pixels and the sensor material of the thermal imager are 256×256 pixels and InSb (indium antimonide), respectively. The specimen shown in Fig. 5 for the experiment is a molded high voltage winding (outside diameter: 32cm, height: 56cm) of the transformer for 22.9kV with 3,922-turn, and its coil is 0.85mm in diameter. The infrared imager is connected to a computer for analysis via the IEEE1394 port (firewire).

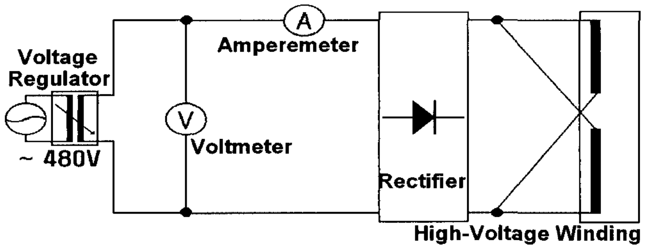


Fig. 6. System block diagram for applying current

Fig. 6 shows the block diagram for applying current. The direct current rectified by a bridge diode was applied for relieving limit of the current by the inductance of the winding, 2.7H.

The program shown in Fig. 7 was made for the analysis and the acquisition of thermal images.

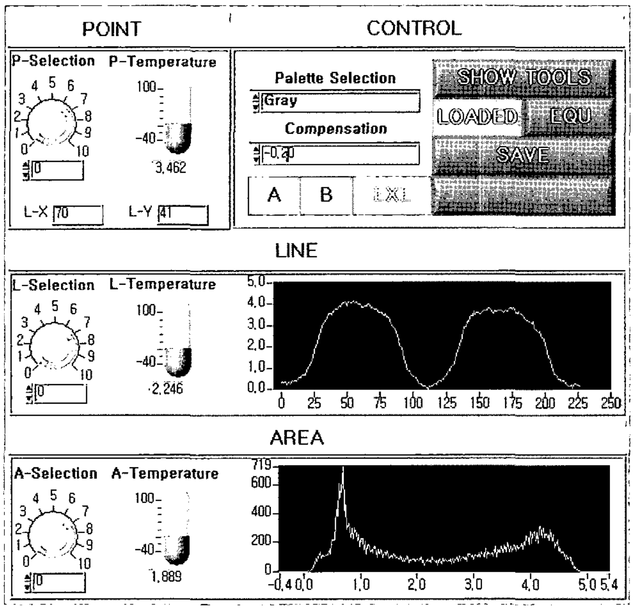
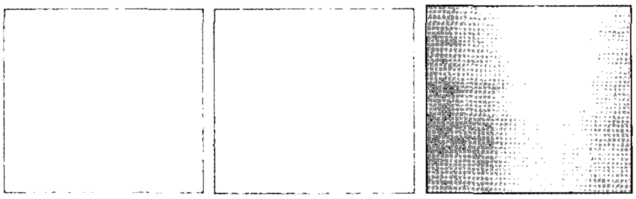


Fig. 7. Program to analyze, acquire and save thermal image

3. Results and Discussion

Fig. 8 is the result images tested by the heat injection method shown in Fig. 3. Fig. 8(a), (b) and (c) are the image of before injecting heat, during injecting heat and difference between (a) and (b) respectively. Because the thermal capacitance of the transformer high voltage winding was large and half the rated current (2.5A) was applied to the winding, the 2 halogen lights were not enough to disturb thermal distribution on the surface of the winding. As a result, the defects of only the surface were detected but the defects of the subsurface were not detected.

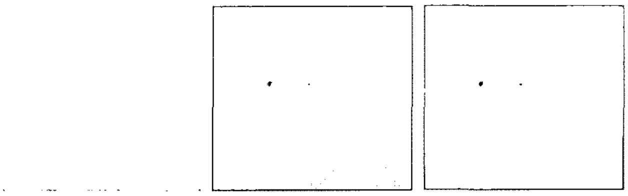
The heat injection of large energy is required to detect the defects of the subsurface. But this method is not suitable to the electrical insulator because the winding may be deteriorated by injected heat.



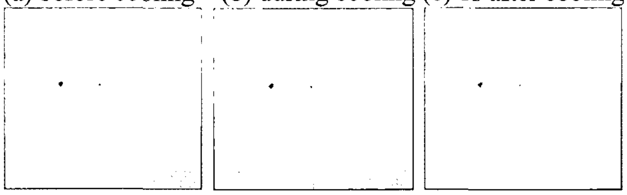
(a) before injecting (b) injecting (c) different image

Fig. 8. Test results of heat injection method

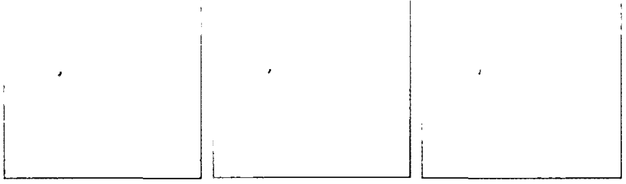
The cooling method using compressed air shown in Fig. 4 is an alternative method to prevent stress by injecting large heat energy. A compressor with the peak pressure of 8kPa was applied for cooling of the winding surface. The defects of the surface and the subsurface were able to be detected by analyzing the thermal contrast of the surface cooled by compressed air.



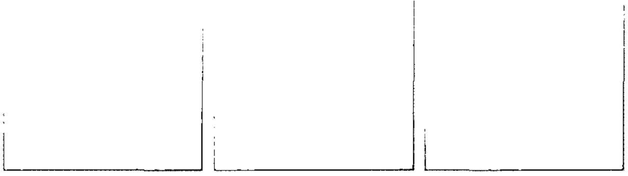
(a) before cooling (b) during cooling (c) 1s after cooling



(d) 2s after cooling (e) 3s after cooling (f) 4s after cooling



(g) 5s after cooling (h) 6s after cooling (i) 7s after cooling



(j) 8s after cooling (k) 9s after cooling (l) 10s after cooling

Fig. 9. Test results of cooling method

Fig. 9 presents the test results obtained by the cooling method. The thermal images are the differential images between a thermal image during cooling and each thermal image obtained every second after cooling. The images have the information on the variation of thermal contrast in the surface with time. The information was acquired from the reheating process by heat generated due to current applied with the circuit of Fig. 6.

The defects of the subsurface were analyzed from the result images. In Fig. 9(b), defects of the surface are notable, and thermal contrast is dropped with time and is considerably dropped in Fig. 9(l). But thermal contrast that was not shown in Fig. 9(b) was detected in Fig. 9(h). This result indicates that the discontinuity of the subsurface can be detected by the active thermography using the cooling method.

4. Conclusions

Because conventional thermography for electrical facilities has been used in passive thermography, only the defect with thermal variation was able to be detected.

In this paper, to detect the defect without thermal variation active thermography was used, which had thermal perturbation by injecting heat or cooling. The heat injection method demanded heat injection of a great amount of energy to detect the defect of the subsurface because the winding of the molded transformer generated significant heat energy. Therefore, the heat energy of halogen lights was not enough to detect the defect of the subsurface. Because the cooling method using compressed air was able to control a large variation of heat of the surface, the discontinuities of the subsurface were able to be detected.

The heat injection method and the cooling method were able to detect the discontinuity of the surface and the subsurface that was not detected by the conventional passive thermography. The heat injection method was limited, controlling heat energy. Heat injection of large energy might become the cause of deterioration. But because the cooling method used compressed air of room temperature, the method was able to control large heat energy.

Therefore, practical use of the active thermography will be able to not only detect the temperature variation by overload, loose terminal and a bad contact pertaining to the rise in temperature but also the discontinuity without thermal variation.

Acknowledgement

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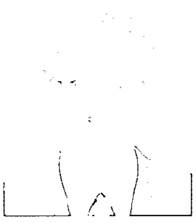

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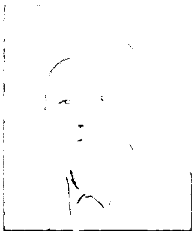

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