Thermal Analysis of the Natural Convection Cooling Type Transformer

Yeon-Ho Oh†, Ki-Dong Song* and Jong-Ho Sun*

Abstract - The life expectancy of a transformer largely depends on the temperature-rise it experiences. If the temperature-rise exceeds limits specified in the design standards, the aging of insulating materials is accelerated and the capability of the cooling medium is deteriorated. Consequently, applicable limits for the temperature-rise are essential in designing the transformer and the coolers, demanding the estimation of the transformer's thermal behavior. In order to analyze the temperature characteristics of the transformer, numerical analysis by way of the commercial CFD code has been carried out, and temperature-rise testing to verify computed results was performed. The results obtained in this study show that there is a good agreement between computed outcomes and experimental outcomes.

Keywords: natural convection, back-to-back method, thermocouple, heat source, heat transfer coefficient

1. Introduction

The life of a transformer is mainly governed by the temperature characteristics within the equipment. Applications of loads in excess of the name-plate rating of the transformer involve some degree of risk. Transformer Loading Guides are intended to identify the risks to the operator and establish limitations which, if applied, will minimize these risks. The thermal limits refer to the top oil and the hottest spot of the winding temperatures.

These temperatures affect the rate of aging i.e., gradual deterioration of the properties of the insulating materials. The higher the temperature, the greater the degree of aging. So, it is essential that the thermal design to reduce these risks be considered during the development of a transformer.

For many years, the cooling design of power transformers largely consisted of the determination of average winding temperature rise above the mean oil temperature rise. The accepted formulae for this purpose are mainly empirical [1]. This practice presented difficulties of detailed temperature distribution in the winding and uncertainty resulting in overloading of the transformer, thus provoking rapid aging of the insulation.

Recently, however, owing to the rapid progress in computer-aided design, the thermal analysis of transformer windings clearly demonstrates that the detailed temperature distribution and the exact location of a hot spot in the winding can be predicted accurately by the numerical method [2, 3].

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Accordingly, numerical analysis for the temperature characteristics of a power transformer has been carried out in this study. The paper deals with this numerical analysis for the thermal behavior in a layer type coil of a transformer, using a commercial program. Temperature rise testing to verify results of the numerical scheme have been performed.

2. Temperature Rise Test

2.1 Model Transformers for Test

The test method employed in this study for temperature rise measurement is the back-to-back method. In this method, two transformers, one of which is the transformer being tested, are connected in parallel and excited at the rated voltage of the transformer being tested. By means of an injected voltage, rated current is made to flow in the test transformer.

Two model transformers for testing temperature rise are instrumented. With the exception of the cooling medium and the duct size within the windings, all specifications are identical. The detailed specifications of the instrumented transformers are shown in Table 1. α oil and β oil were used for the cooling medium, which have similar characteristics with the exception of viscosity ; β oil has larger viscosity than α oil. The cooling system is natural oil flow and natural air cooling. In this system, the oil entering the inlet is heated within the winding. It then streams upwards and exits the outlet. The oil is cooled in the radiator after exiting. The oil enters the inlet repeatedly. The heat generated within the winding is dissipated through radiators contacted with ambient air by this circulation.

2.2 Sensors

Sensors used in the experiments are thermocouples, which are small in size and can be easily handled. In using the thermocouples, direct measurements are usually very difficult because a winding voltage is imposed on the measuring leads of the thermocouples, requiring their insulation [4]. For this insulating problem, leads of the thermocouples were molded with epoxy and shielded with Kapton film, which has good thermal conductivity and excellent insulation characteristics (Fig. 1).

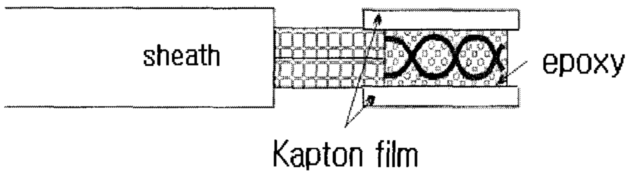


Fig. 1 Thermocouple for temperature measurement

Locations to measure temperature of the winding are shown in Fig. 2. Sensors were also set up in the oil at the cooling system's inlet and outlet.

The transformers were placed on plastic plates and leads of the thermocouples were drawn out from a pipe on the tank cover using a lump of paper insulation so as not to contact directly with the tank structure. Then they were connected to the measuring equipment on a stand, and carefully insulated from the earth by insulators so as to avoid contact with earth potential metals.

Table 1 Specifications Of The Model Transformers

Specification	Model 1	Model 2
Rated Power	400 kVA	
Rated Voltages	6600 / 220 V	
Phase	1	
Cooling Medium	α oil	β oil
Cooling Method	Natural Convection	
Duct Size (L.V.)	3 mm	4 mm
Duct Size (H.V.)	5 mm	6 mm

A fully installed measuring system is presented in Fig. 3, including data-acquisition-system, model transformers and PC to control measured data. This equipment was installed indoors so that radiant heat could be ignored during the calculation of temperature rise.

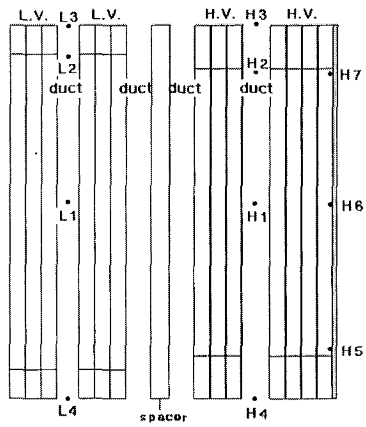


Fig. 2 Sensor locations within transformer

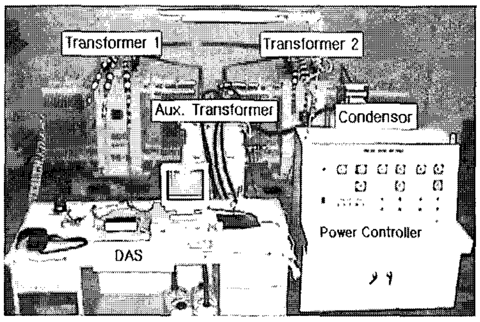
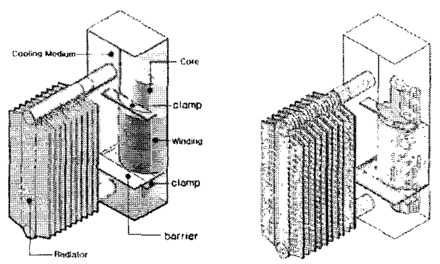


Fig. 3 Back-to-back system for measurement temperature

3. Numerical Analysis

To analyze the thermal behavior of model transformers, a 3 dimensional grid was generated using 3D software. Because of the symmetrical 3 dimensional shape, only a quarter of a real transformer was used for calculation (Fig. 4 (a)). By adopting the symmetrical model, we can save computation time due to the reduction of total number of grids to be calculated. The number of grids used in calculation was about 600,000.

The transformer as shown in Fig. 4 consists of cooling medium, silicone-iron for core, Aramid paper for insulation and copper for coil. These characteristics of these materials have been considered in the calculation. The heat sources of the winding and the core are given in Table 2.



(a) 3 dimensional figure (b) Grid

Fig. 4 Model for calculating

Table 2 Heat Source of Winding and Core

Item	Heat Source [W/m^3]
L.V. winding	626,925
H.V. winding	674,003
Core	18,049

Almost all of the heat generated within the winding is dissipated through the radiator and contacted with the air. Therefore, the boundary condition between the radiator and the surrounding air should be taken into account. As well, the radiant heat could be neglected because experimental equipment was installed indoors. In this calculation, the empirical value of the heat transfer coefficient was used in the boundary region. (The bottom of the transformer tank is defined as being in adiabatic condition.) .

4. Discussion of Computed Results

The values of the temperatures at various points of the windings and the radiator of model 1 are illustrated in Fig. 5. The computation was performed at rated power. The maximum temperature of the coil was 384K at H.V. upper position, and the ambient temperature was 296K.

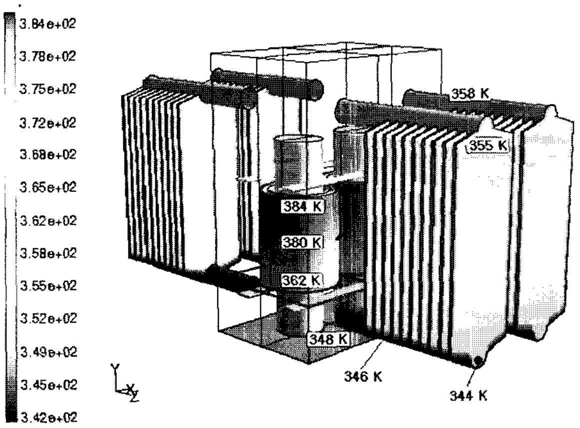


Fig. 5 The values of the temperatures for model 1

The analyzed oil temperatures within the H.V. duct compared with the measured ones are indicated in Fig. 6. The hottest temperatures in accordance with ratio of rated load are also shown in Fig. 7. In this comparison, the measured temperatures in the upper winding are somewhat higher than the calculated ones. However, the calculated values agree well with the measured values.

5. Conclusions

The numerical technique was applied to a typical natural convection transformer to analyze temperature characteristics, and the measurement of temperature to verify the results of the numerical scheme was performed.

For model transformer 1, the oil circulation within the transformer has been clearly presented by numerical analysis. The calculated temperature has indicated a good agreement with the measured values, and has validated the reliability of the described numerical scheme.

The analyzing technique for thermal characteristics proposed in this paper could be a useful and effective method to verify the cooling system in transformers.

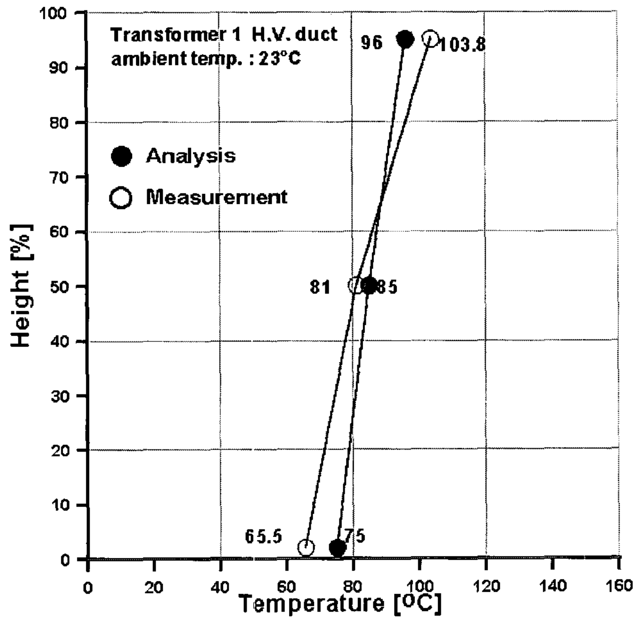


Fig. 6 Temperatures within H.V. duct(Transformer 1, H4-H1-H2)

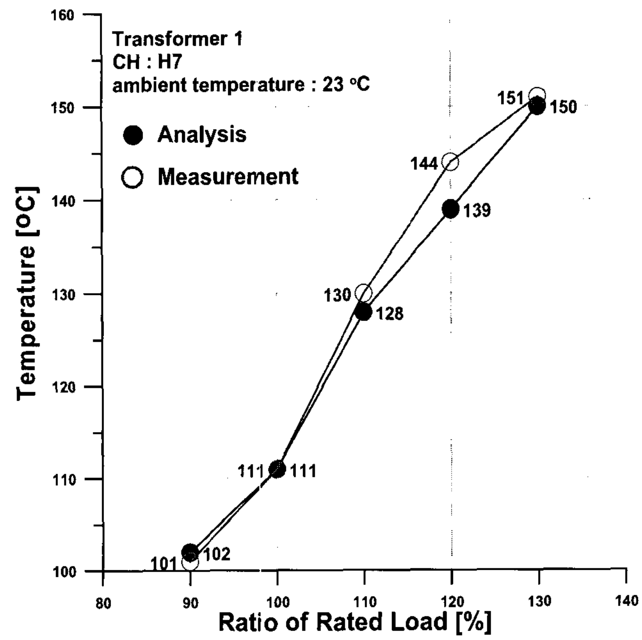


Fig. 7 The hottest temperatures at ratio of rated load

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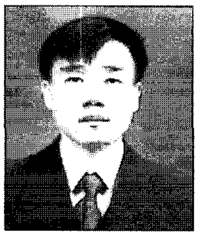

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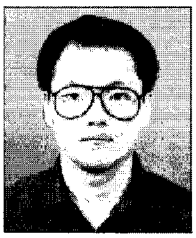

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