ANALYSIS OF HEAT EXCHANGER EFFICIENCY FOR AN ELECTRIC POWER TRANSFORMER

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Abstract. *The objective of this paper is to analyse through the Finite Elements Method (FEM) the efficiency of heat exchanger with forced cooling circuit by type oil-air RTCF 200 kW for electric power transformers. The Finite Elements Analysis was performed using SolidWorks 3D CAD Design and FLUENT 6.3.26 Software. A 3D model of the studied geometry was generated based on the designed data. The FEM results were compared with the results of tests carried experimentally. The obtained results offer important information for economical design of the power transformers to reduce the cost of manufacturing transformers.*

Keywords: *power transformer, heat exchanger, thermal efficiency, engineering design*

1. INTRODUCTION

The power transformer is one of the most important components in a power system. The power transformers design can be considered as one of the most complex electrical equipments design problems, which requires a complex interdisciplinary collaboration between engineers, analysts and designers [1, 2].

The power transformer optimization is an important research field at international level. The optimum design through the Finite Elements Analysis of a power transformer can significantly reduce the weight, the power consumption, the cost of manufacturing, and increase security and even the reliability of the entire transformer unit [3, 4]. In order to increase transformer operational efficiency and minimize the probability of an unexpected outage, several on-line and off-line monitoring systems have been developed [5, 6, 7]. An important problem at the power transformer design is to optimize the heat exchanger [8, 9].

2. CONSTRUCTIVE AND FUNCTIONAL ANALYSIS OF THE OIL RADIATOR BY COMB TYPE FOR RTCF 200 KW

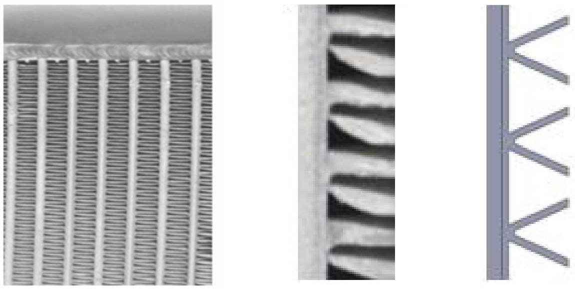
The heat exchanger by type RTCF 200 kW is used for cooling the transformer insulating oil type Tr 30 used in electric power transformer (Fig. 1) [10].

The cooling system used is based on the forced movement of transformer oil into a heat exchanger type by comb, made of aluminum alloy and the forced air movement over the first hydraulic circuit made of a group of three electro fans.

In constructive terms, the cooling battery consists of six identical modules located in the frontal position of three fans, all united inside a metal casing, as can be seen in Fig. 2. In particular, each module contains 36 identical cooling circuits, as can be seen in Fig. 3a and Fig. 3b. In Fig. 3c is shown a 3D model for FEM study.

Figure 1. The power transformer.

Figure 2. The cooling battery.



a) b) c)

Figure 3. a) The cooling circuit; b) 1/2 a cooling element; c) 3D model for FEM study.

In the studied mechanical structure it is noted the symmetry of both constructive cooling circuit and the symmetry of flow phenomenon.

3. THE INSTALLATION FOR EXPERIMENTAL MEASUREMENTS

The heat exchanger geometry is complex in terms of construction, and practically is very difficult to introduce an efficient theoretical method for assessing the heat exchange efficiency of the cooling oil flowing through the radiator and the environment only by calculation. Following these reasons, an experimental investigation was adopted on the installation manufactured by ICMET Craiova, Romania [10].

In this context the heat exchanger was tested at a range of operating regimes. The measurements were made at an ambient temperature T = 22 [°C]. The experimental results obtained were compared with results determined by the finite elements analysis.

4. 3D MODELLING OF COOLING CIRCUIT OF HEAT EXCHANGER

The analyze through the FEM of the efficiency of heat exchanger with forced cooling circuit by type oil-air RTCF 200 kW for electric power transformer was made based on the transformer drawings, the component materials, considering the extreme functioning conditions prescribed by the manufacturer [10].

This database constitutes the main input data in the Finite Elements Analysis. It is considered that upstream of battery cooling the air input through the radiating coils of cooling elements with a constant speed over the whole aspiration surface of the batteries, situation confirmed by experimental measurements.

At the results of simulation calculation, appears deviations caused by: imperfection to achieve of constructive battery (concerning the deviation form of radiant coils); the solder mode between the coils with radiant elements; and inadequate slots tightness relative with the casing. These deviations generate flow disturbance, change the resistance corresponding the channels between the elements and a different heat transfer on each component cooling battery.

The 3D geometrical model consists of two subregions: a) the first subregion (the transformer and the cooler) was discretised into almost 400,000 Hex8 elements; b) the second subregion (the surrounding air) was discretised into almost 450,000 Hex8 elements. Taking into account the average mesh quality, the geometrical model had a value less than 0.05, which is a better value than recommended by the FLUENT manufacturer (0.4) [2].

5. THE FACTORS THAT GENERATE ERRORS IN NUMERICAL CALCULATION OF HEAT EXCHANGER

The factors that generate errors in numerical calculation, in acceptable limits, of heat exchanger are: a) the deformation of cooling wings from assembly, that changes the aerodynamics flow and the heat exchange; b) the imperfect adjustment of the radiating wings of 1/2 a cooling element that increases the contact surface; c) the partial closure of slit input in hydraulic circuit of 1/2 a cooling element covered by welding, which disrupt the hydraulic flow.

As a consequence appear different flow regimes from a cooling element to another with major changes in the flow process at the input slots (flow, pressure, flow rate etc.) that are directly reflective in the heat dissipative process. Following this aspect it is conclude that is difficult to make an exact calculation of heat exchange because each element of the radiator cooling structure (with a total number of 216 circuits), have different: configurations, flow regimes and heat exchange. Taking into account these factors in numerical analysis are determined the average values of physical quantities and three-dimensional modelling will not consider these deviations from execution.

The transformer oil has a turbulent flow characteristic. To analyze the thermal modeling of the power transformer, the analogy between thermal and electrical process was employed - in our case, the top-oil temperature model [7].

6. THE ANALYSIS OF THERMAL EFFICIENCY OF HEAT EXCHANGER USING THE FINITE ELEMENTS METHOD

6.1 The initial data

First, considering the stationary work of electric power transformer, was determined and measured experimentally the next data:
- the pump flow: $Q_u = 0.0125$ [m^3/s];
- the section of interior channel slot of a cooling element: $S_0 = 5.6\ 10^{-5}$ [m^2];
- the number of elements in the battery cooling: $n = 36$;
- the number of batteries cooling: $N = 6$;
- the transformer oil flow characteristics in the input channel slot of cooling element are: $T'_u = 352$ [K], $p'_u = 54$ [kPa], $v_u = 1.033$ [m/s];
- the air characteristics circulated in the input cooling circuit are:
$T'_a = 294$ [K], $p'_a = 101.325$ [kPa], $v_a = 6.83$ [m/s];
- the surface roughness of cooling element walls and radiating coils is: $Rz = 100$ [µm].

6.2 The data for simulation

The Finite Elements Analysis was performed using SolidWorks 3D CAD Design and FLUENT 6.3.26 Software [11].

Because the cooling circuit presents three linear sectors (individually marked and shown in Fig. 4, Fig. 5 and Fig. 6), the simulations result will be shown for each of them. In numerical calculation is excluded the heat losses that occur in the bends between the linear sectors.

Let's mark by L, the linear coordinate measured along the axis of symmetry of cooling element (the origin is fixed at the section of oil input to the first sector in the oil flow sense) and with H the sector thickness in the air flow sense.

The linear sectors are contained in next limits:

- Sector 1: $L = 0$ .... 800 [mm], $H = 0$ .... 30 [mm];
- Sector 2: $L = 900$ .... 1800 [mm], $H = 30$ ... 60 [mm];
- Sector 3: $L = 1900$ ... 2700 [mm], $H = 60$ ... 90 [mm].

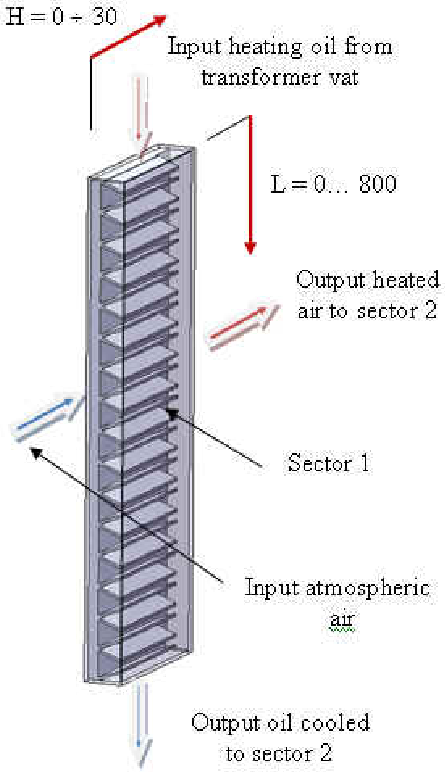


Figure 4. The sector 1.

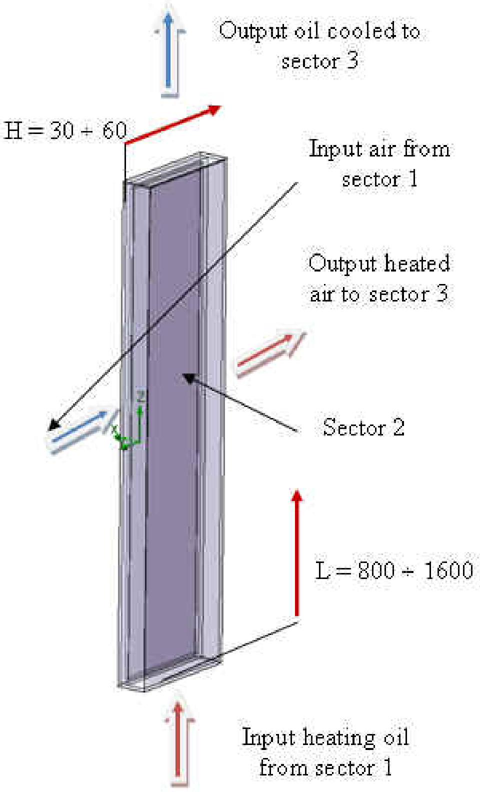


Figure 5. The sector 2.

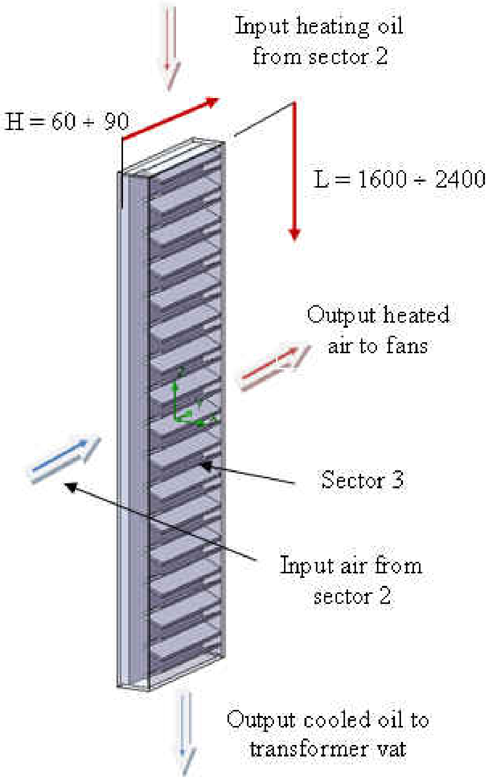


Figure 6. The sector 3.

6.3 The results simulation using the FEM

The average oil temperature given by the surface in flow channel section at ΔL = 100 mm along the length L coordinating and for the air temperature on the section channel corresponding with the mean ΔL was determined and noted [10]. The velocity and temperature field distribution for sector 1, $L = 0 \div 100$ mm, are shown in Fig. 7 and Fig. 8; and for sector 3, $L = 2300 \div 2400$ mm, in Fig. 9 and Fig. 10.

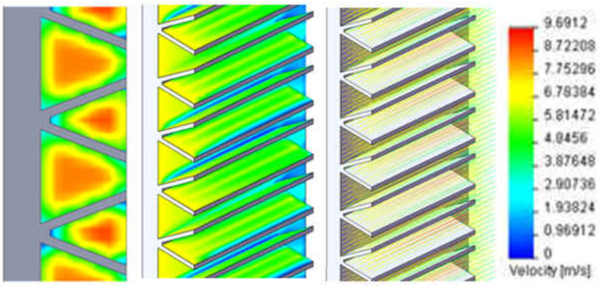


Figure 7. The velocity distribution for sector 1, $L = 0 \div 100$ mm.

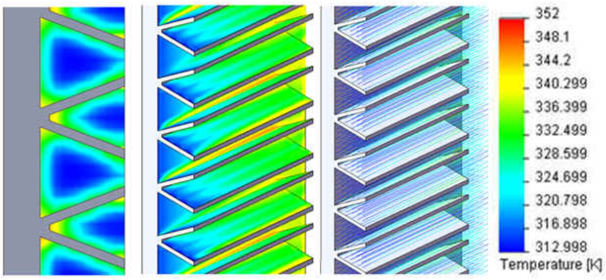


Figure 8. The temperature distribution for sector 1, $L = 0 \div 100$ mm.

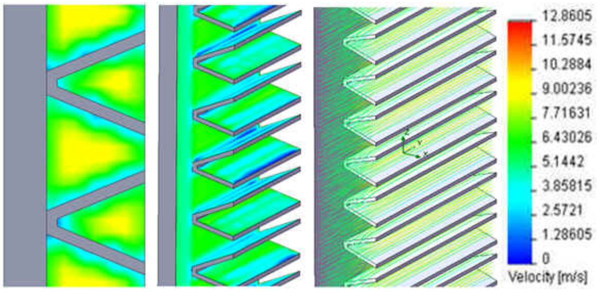


Figure 9. The velocity distribution for sector 3, *L* = 2300 ÷ 2400 mm.

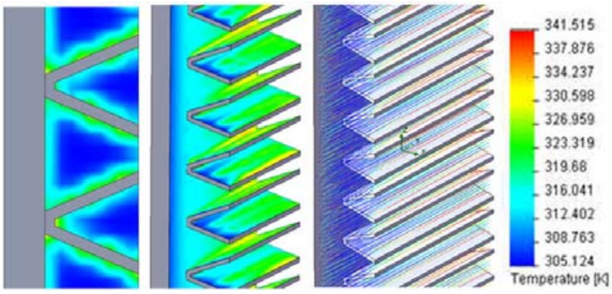


Figure 10. The temperature distribution for sector 3, *L* = 2300 ÷ 2400 mm.

7. CONCLUSIONS

Analysis results show that the average oil temperature has a cooling equal with ΔT = 352 [K] - 341.02 [K] = 10.98 [K]. This calculated value is less with ΔT_1 = 1.03 [K] than the measured value.

Analysis results show that the average air temperature has a cooling equal with ΔT = 313.99 [K] - 294 [K] = 19.99 [K]. This calculated value is less with ΔT_2 = 3.2 [K] than the measured value.

The transformer oil cooling efficiency is calculated by the relation:

$$\Phi_u = Q_u \cdot \rho_u \cdot c_{pu} \cdot (t_u' - t_u'') \qquad (1)$$

where:
- Q_u [m^3/s] is the volume flow of transformer oil;
- ρ_u [kg/m^3] is the oil average density in the temperature range t_u'... t_u'';
- c_{pu} [J/(kg·K)] is the oil average mass specific heat at constant pressure in the temperature range t_u'... t_u''.

The transformer oil cooling efficiency calculated by the relation (1) using the numerical values obtained by simulation is:
- Q_u = 0.0125 [m^3/s];
- ρ_u = 835 [kg/m^3];
- c_{pu} = 2150 [J/(kg·K)];
- ΔT_{oil} = (t_u' - t_u'') = 352 [K]- 341.02 [K] = 10.98 [K].

$\Phi_u = Q_u \cdot \rho_u \cdot c_{pu} \cdot (t_u' - t_u'')$ = 0,0125·835·2150·10.98 = 246174 [W] = 246.17 [kW]

So, the heat exchanger performs an exhaust heat oil Φ_u = 246.17 [kW] that is higher than the minimum $\Phi_{u\ minim}$ = 200 [kW], for which it was designed.

The proposed method for analysis of thermal efficiency of heat exchanger using the FEM has some advantages as follows: a) It requires no investment or cost of operation being very economical; b) It gives a better understanding of the thermal performance of the transformer and can be built up before the transformer is manufactured. Thus, the model can be used in economical design of the power transformers to reduce the cost of manufacturing transformers.

8. ACKNOWLEDGMENTS

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