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# TEMPERATURE PROBLEMS IN THE FURNACE TRANSFORMER AGGREGATES, CONSISTING OF THE MAIN AND THE VOLTAGE-ADDING TRANSFORMER

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## ABSTRACT

The paper discusses the distribution of the thermal field in the magnetic core of a mono-phase transformer aggregate including the main and the voltage-adding transformer. The main aim of the analysis is to locate the most overheating section of the magnetic system studied and to investigate this overheat in the different overloads. The experimental data are compared with the simulation ones and the resulting error is less than 5 %.

***Index Terms*** **–** thermal field, mono-phase transformer aggregate, overheating

## 1. INTRODUCTION

The furnace transformers and transformer aggregates work continuously under variable load which changes from open-circuit to short-circuit. In addition to this the load is not symmetrical. Under these circumstances this type of transformers requires complete analysis of electrodynamic and heat problems.

Modern application of electrothermics in industry is connected with development an improvement of new more powerful furnace transformers and aggregates. With increasing of power the heat problems increase, too, so the transformers must be thermally designed is such a way that the temperature of every part of them to meet standard values under given guaranteed open-circuit to short-circuit looses. Otherwise local overheatings could be arisen.

The investigations show that these overheatings frequently take place in magnetic cores.

The transformers losses release a heat in transformer windings. According to effective standard maximum allowed temperature values of magnetic system is $115^{0}\ C$ (on surface) and $95^{0}\ C$ (for transformer oil). If temperature rises with $8^{0}\ C$ then the life of transformers decreases up to two times.

Transformer oil conducts the heat of active parts of transformer to the walls of the tank and from there – to the air. The hot layers of the oil move to the upper part of the tank while colder ones move to lower part. Since the temperature difference between tank walls and air is dozens of degrees the carrying of the heat is fulfilled both by convection and radiation.

The high temperature on the surface of the core could deteriorate the performance of both transformer oil and the hard insulation (electro insulation cylinders). A possible result could be “fire” in the steel.

## 2. PROBLEM STATEMENET

The transformer is the non-homogeneous object with respect to the heating processes. The problem connected with heating could be solved if the following is given: quantity of heat release for unit time, its location and possibility of its taking away. It is known that there are open-circuit losses in operating mode of a transformer, and the losses depending on property of materials (steel, cooper, aluminum, etc.) and also of the design of the transformer.

Open-circuit losses are connected with hysteresis losses and eddy current losses while short-current losses include windings losses and additional losses of leaking field. Serious overheating problems arise with increasing the power of transformers.

In practice, for decreasing the total losses and taking away the temperature, suitable coolers are used. In spite of all that has been told, it is very difficult a temperature of real transformer to be measured.

In this paper an attempt for an analytical investigation of the temperature distribution in the core of an oil transformer aggregate is made. A single-phase furnace transformer aggregate with main transformer (MT) and voltage-adding transformer (VT) is considered [1].

A common magnetic circuit for both transformers is used (Fig. 1).

Magnetic system for both transformers (MT and VT) consists of three cores. The three windings of the MT (1, 2 and 3) are on the one of the cores (b). The two windings of VT (4 and 5) are on the other core (a). The third core (c) is without any windings. This core usually is called a magnetic shunt. The sum of magnetic fluxes $\Phi_b + \Phi_a^{'}$ and their difference $\Phi_b - \Phi_a^{''}$ of magnetic fluxes are closed through it.

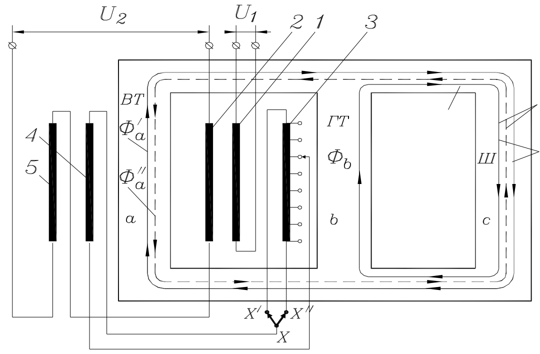

*Figure 1 Electrical circuit of a transformer aggregate with three-core magnetic system with reversion of control winding*

The following equalities for magnetic shunt are valid:

$$\Phi_c' = \Phi_b + \Phi_a' \qquad (1)$$

$$\Phi_c'' = \Phi_b - \Phi_a'' . \qquad (2)$$

Here, the winding 1 is primary one that excites constant magnetic flux. The windings 2 and 5 are secondary ones for the MT and VT. They are connected in series and in this way they form the secondary windings of the entire transformer aggregate. Winding 3 of MT activates the VT winding 4 which excites a magnetic flux in its core. The magnitude of the flux depends on the state of the control winding. In the first case in the core (c) the inductance and open-circuit losses increase while in the second case they highly decrease - as a result the dimension of the cross-section of the core could be smaller. If the transformer works in “heavy” mode and of the same time there is an overloading, i.e. short-circuit state in which practically aggregates operate longer, then both the inductance and open-circuit losses considerably increase.

Exactly in this case is quite possible a local overheating of the core to occur. As a result both the core lamellae and yoke insulation deteriorates, also the insulation properties of the transformer oil worsen.

The purpose of this paper is to analyze the distribution of a temperature field in a given magnetic circuit, i.e. to localize the most thermally loaded parts and to investigate the overheating in different cases of overloadings.

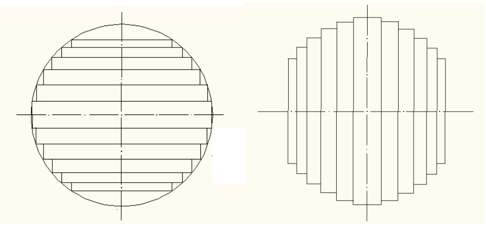

*Figure 2 The shape of the cross-section of the core and yoke of the power transformer aggregate*

In practice there are different designs of magnetic cores. In spite of the design each magnetic system consists of a core and yoke. The shape of the cross-section of the core and yoke of a power transformer aggregate is given on Fig. 2.

Steel lamellae are suitable arranged in order to obtain a necessary form (Fig. 3).

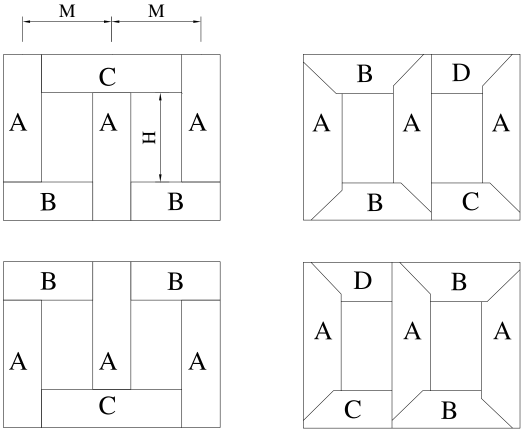

*Figure 3 Steel lamellae of the core and yoke of the power transformer aggregate*

Overheating could be decreased with the so-called cooling grooves.

During the design process of the core usually one aims at maximum possible effective cross-section area because of better usage of the space in transformer volume.

Tightening the core can be done in two ways – with wooden plates and cotters when the diameters are no so big (Fig. 4) [3] and with bandages, otherwise.

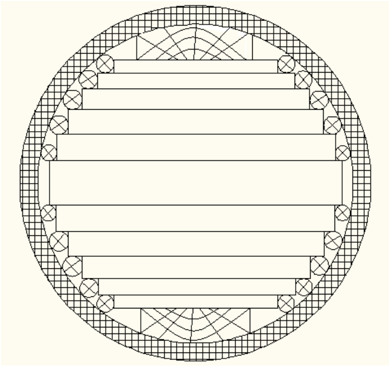

*Figure 4 The cross-section of the core tightened with wooden plates and cotters*

Tightening the yokes is done with yoke beams which have very sophisticated shapes.

Having in mind everything that has been said it is clear that all the tightening elements (plates, cotters, beams, etc.) covered and thermally isolated parts of the surface of the core which frequently leads to local overheatings – “fire” in the steel.

## 3. MATHEMATIC MODEL OF THE PROBLEM

Suppose that the temperature field at the core is two-dimensional one and specific magnetizing losses in all parts of the core and the yoke are constant. The non-linearity of the thermal process is not taken into account.

Generally, the core cross-section area is divided into rectangular areas which coincide with the appropriate cross-cooling groove made of electro insulating material. In this way the problem is independently solved for each area. If one uses the symmetry of the core cross-section, resp. yoke then the problem could be solved for only ¼ area.

The process of heat transferring from separate parts of the transformer to the air is according to the laws of heat-exchange, i.e. it is subject to non-reversible processes for heat distribution in space.

Actually this distribution is exchange if internal energy between separate parts of a transformer.

The process of heat distribution can be given by the following equation:

$$\lambda_x \frac{\partial^2 T}{\partial x^2} + \lambda_y \frac{\partial^2 T}{\partial y^2} + q = 0 \qquad (3)$$

with boundary conditions:

$$\frac{\partial T}{\partial n} = 0 \qquad (4)$$

$$\lambda_x \frac{\partial\, T}{\partial x} n_x + \lambda_y \frac{\partial\, T}{\partial y} n_y + \alpha (T - T_0) = 0 \qquad (5)$$

where:

$T$, ${}^0C$ is the temperature of the analyzing area;

$\alpha$ is the coefficient of thermal conductivity over the lamella length;

$T_0$, ${}^0C$ is the temperature of the oil and it is constant over the whole boundary;

$n_x$, $n_y$ are unit vectors of the boundary areas.

In the process of investigation the coefficient of thermal conductivity for different points of the core is different. In places with woolen cotters it is thought to be zero, otherwise – it is nonzero.

## 4. PROBLEM SOLUTION

The mathematical model considered is applied to the real transformer with power 2 MVA and voltage 20kV. The diameter and the vertical section of the magnetic core is 280 mm and 512 cm$^2$, respectively for the core and yoke with two cooling channels with 7 steps.

The investigation process shows that the overheatings in the most external layer of the magnetic core lead to deteriorate of the electro insolating properties of the transformer oil. In this reason, it was made the measurements of the core temperature on this area. They are realized with thermocouples. The heat transfer in the transformer is simulated by use of QuickField. The temperature distribution in the magnetic system is shown in Fig. 5.

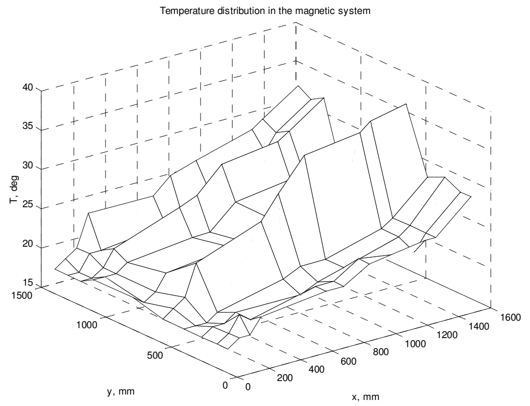

*Figure 5 The temperature distribution in the magnetic system of the transformer considered*

The maximum difference between the measured and simulated results is 5%.

## 5. CONCLUSIONS

The results about the thermal field distribution confirm the theoretical ones that the overheating parts of the transformer aggregate considered are the most external layer of the magnetic core. These results, helps designer to decide whether to use cooling grooves or not.

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