ASPECTS REGARDING NUMERICAL MODELING OF INDUCTIVE HEATING PROCESS FOR LOW VOLTAGE ELECTRICAL CABLES

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În această lucrare se prezintă un algoritm privind modelarea numerică a încălzirii prin inducție a cablurilor electrice de joasă tensiune .Rezultatele obținute vor putea fi folosite la studierea proprietăților izolației electrice a cablurilor. Se poate face o corelare, cu efectul termic asupra izolației cablurilor, produs de curentul electric, de sarcină sau de defect, ce trece prin cablul respectiv şi care duce la degradarea izolației acestuia .Folosindu-ne de rezultatele simulării numerice putem echivala efectul încălzirii inductive, care constituie un test la scara redusă, cu efectul încălzirii izolației în regim normal sau de defect în diferite situații şi regimuri de funcționare .Cablul studiat este de sectiune cilindrica cu izolatia din PVC.

In this paper is presented an algorithm for numerical modeling of inductive heating process for low voltage electrical cables.The results will be used in studies of cables electrical isolation proprieties. It is possible to do a correlation between thermal effect on cables isolation, produced by electrical current witch goes over cable and lead to isolation damage.Using numerical simulation results, we can equalise inductive heating effect witch is a test with isolation heating effect in normal condition.The cable for study is of cylindrical section with PVC insulation

Keywords: electrical cables, induction oven,numerical simulation, PVC insulation

1. Introduction

The measurements purpose is to obtain information on isolations, especially on the new ones, within a short time range, concerning elimination of the most initial defects and to allow establishment, isolation systems manufacturing processes.

Warming through the phenomenon of electromagnetic induction principle is based on electromagnetic field penetration in the conductive material under the magnetic field varies in time, it is studying a sample of heating cable in an induction oven.

Eddy currents create induced electromotive tensions leading to the heating cable Joule-Lenz effect.

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By numerical simulation equivalence is obtained by heating the oven with induction heating under normal operating conditions.

2. Conductor Cable Heating in an Induction Oven

Electromagnetic Field Problem

It is considered the metallic part of the cable of cylindrical form (fig. 1). The cable is situated in a magnetic field variable because of the inductive oven.

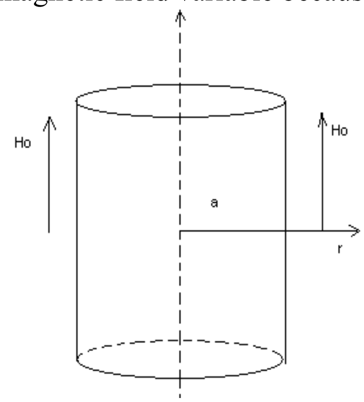


Fig.1. Cylinder in variable magnetic field

Electric fields, magnetic and current density values are important only near the surface conductor, their actual values decreased exponentially with distance from the surface conductor.

Depth of penetration δ is the distance from the conductor surface should be evenly distributed current total for the loss of active power to be equal to the actual case of uneven distribution of power.

Penetration depth of magnetic field in studied cable, is given by relation:

$$\delta = \sqrt{\frac{2}{\omega\mu\sigma}} \tag{1}$$

$\omega = 2 \cdot \pi \cdot f$, pulse alternating current;

μ = magnetically permittivity of the conductor material;

σ = electrical conductivity of the material.

Because the phenomenon of electromagnetic induction, associated with the feedback induced currents is current has the tendency to fall with a greater density in peripheral areas:

- Magnetic field intensity within the cable is:

$$\underline{H}(r) = \underline{A} I_0(\underline{\lambda_r}) + \underline{B} K_0(\lambda_r) \tag{2}$$

I_0 and K_0 - Bessel modificated functions of first speta and the second order zero speta.

$$\underline{\lambda} = \frac{1+j}{\delta}. \tag{3}$$

A = magnetic vector potential;
B = magnetic field induction.

Variable in the current injected into a conductor has a different distribution from the current distribution, a phenomenon called pelicular effect. Effect pelicular is the inductive heating basis. It consists of uneven distribution of currents on the conductor material, current density is maximum at the outer surface thereof, in other words the current is to suppress the outside conductor.

- Eddy current will be calculated by relation:

$$\underline{J}_r = -\frac{\mathrm{d}\underline{H}}{\mathrm{d}r} = -\lambda\left[\underline{A}I_1(\underline{\lambda}_r) + BK_1(\underline{\lambda}_r)\right] \tag{4}$$

A = magnetic vector potential;
B = magnetic field induction;
H = magnetic field intensity.

- Complex apparent power flow $\underline{S}$ per unit of heated surface $r = a$, are the expression:

$$\underline{S} = \underline{E}(a)\underline{H}(a) = -\frac{\underline{\lambda}H_0^2 I_1(\underline{\lambda}_a)}{\sigma I_0(\underline{\lambda}_a)} \tag{5}$$

E = electric field intensity
σ = electrical conductivity of the material.

Thermal Field Study

Heat pipe is in place transitional arrangements

- Thermal diffusion is described by the equation:

$$-\operatorname{div}\lambda\operatorname{grad}T + c\frac{\partial T}{\partial t} = p \tag{6}$$

If $\alpha = 0$ obtain homogeneous Neumann conditions.
c = volume heat capacity
λ = thermal conductivity
p = volume density of power which is transformed in the form of electromagnetic heat.

- Boundary condition is :

$$-\lambda\frac{\partial T}{\partial n} = \alpha\left(T - T_e\right) \tag{7}$$

α = coefficient of heat transfer surface
T_e = temperature outside the domain.

If α = 0 obtain homogeneous Neumann conditions and if λ=0 result Dirichlet Boundary condition

The Coupled Model

The electromagnetic field and thermal diffusion problems are coupled because of the temperature dependence of the material properties. The Joule power losses due to the eddy currents represent the heating source in the thermal diffusion problem. The Joule specific power losses depend on the square of the current density and of resistivity, which depends on the temperature. In the same time the thermal problem is nonlinear because of the thermal conductivity dependence on the temperature.

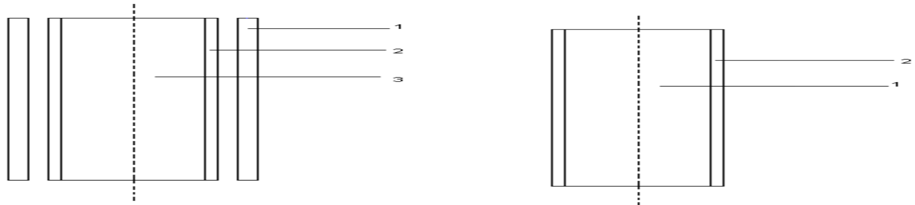
To resolve the coupled set of equations in transitory regime there is developed a numerical model using the finite element method. There is used the discretization with finite element in space leading to first degree differential equations.

3. Consideration on Numerical Modeling of Conductor Cable Heating

By modeling the object of study designed to understand the specific physical quantities and mathematical models characteristic. Electromagnetic field knowledge in any equipment allow global performances calculation for any operating regimes, permanent or transient.

Finite element method involve a global function determination witch represents the phenomenon for study in any point of calculation range. Because this calculation range is divised in many adjacent sub domains, named finite elements, global function is a function assembly associated with every of this elements. The simulation was done with Quickfield 5.6 Student software.

Physically model



a) b)

Fig. 2.

a) Physically model for the induction oven; (1-inductor; 2-isolation; 3-cable)

b) Physically model for cable in load; (1-cable.2-isolation)

• diameter cable d_1 = 42 mm;

• insulation thickness of cable g = 3 mm;

• cable length l = 126 mm;

• diameter inductive d_2=55 mm.

Coil of inductor is assimilated as a conductor with a bulk density of current J = 20MA/m. Frequency of inductor current f = 1000Hz. Initial temperature in the oven T_0 = 300K.

Table 1

	$d[kg/m^3]$	c_p [J/kg·K]	λ[W/mK]	$\rho[\Omega \cdot m]$	μ_r	α[W/mK]
Cu	8933	**380**	**380**	$2 \cdot 10^{-8}$	**1**	**20**
PVC	1300	**1800**	**0,15**		**1**	**20**

4. Numerical Simulation Results in a Cable in Load Heating Process

The cable for study is the same with one witch is heated in induction oven. The head is the potential difference: U = 0.027V. Discretisation has been done by the simulation software in time t = 10800s

Boundary conditions are Neuman condition at conductor-isolation interface and convection at isolation-environment boudary. Initial temperature of surrounding environment has been established at T_0 = 300K.

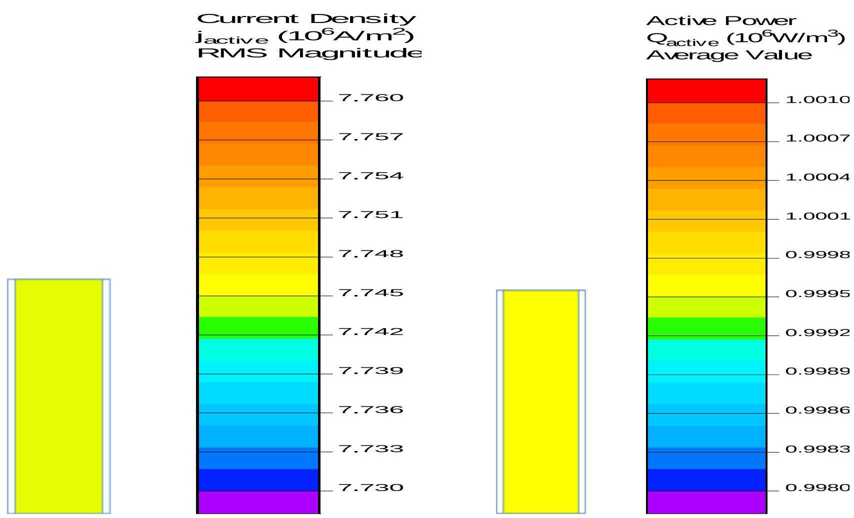


Fig. 3. View current density and power dissipated by the cable assets located in the task studied.

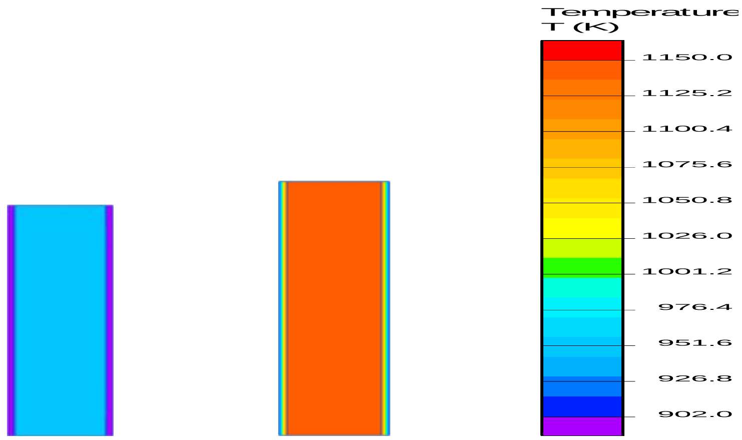


Fig. 4 Viewing thermal field in the cable located in the task at t_1=5500s and t_2=10800s

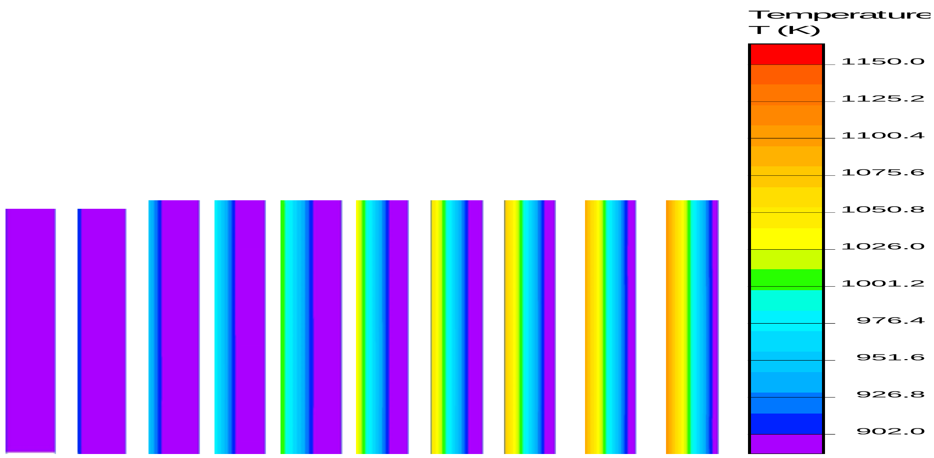


Fig. 5. Viewing the field in thermal insulation layer in different moments of the thermal analysis

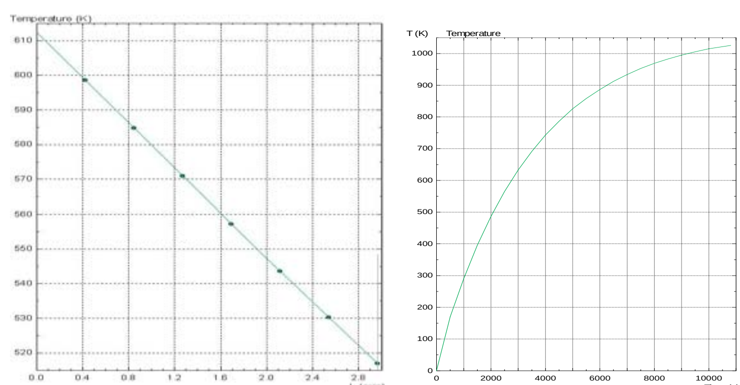


Fig. 6.a) Field variation in thermal insulation layer between A (18,16) and B(21,16) at t = 5500s;
b) Field variation in thermal insulation layer in the coordinates C (23,14)

5. Numerical Simulation Results of Conductor Cable Heating in Induction Oven

Surrounding environment initial temperature from induction oven has been established at T_0 = 300K. Discretisation has been done by simulation software in a period of t = 10800s.

Boundary conditions are Neuman condition at conductor-isolation interface and convection at isolation-environment boudary. At analysis range border it is necessary Dirichlet condition.

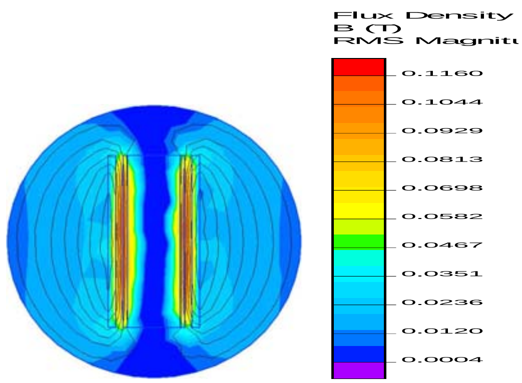


Fig. 7a) View of magnetic field and eddy current density from induction oven

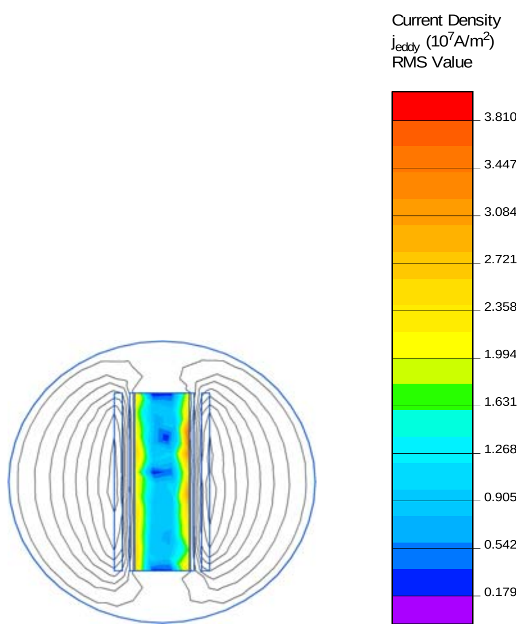


Fig. 7b) View of magnetic field and eddy current density from induction oven

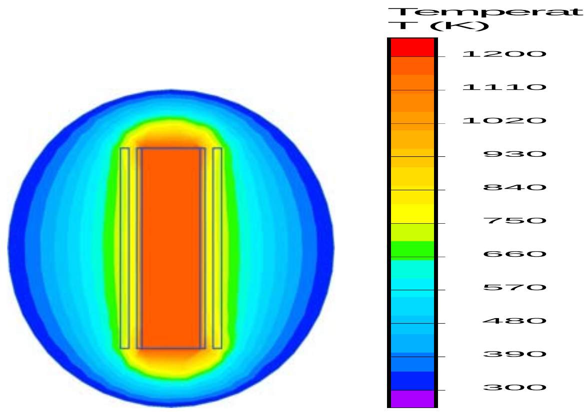


Fig. 8. View of thermal field at time moment t = 8500s .

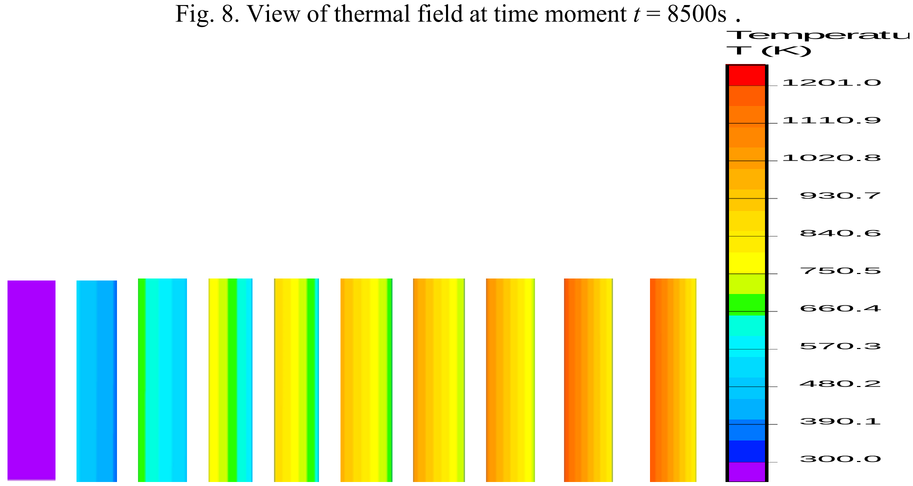


Fig. 9. View of thermal field in cable isolation layer at several time moments of heating

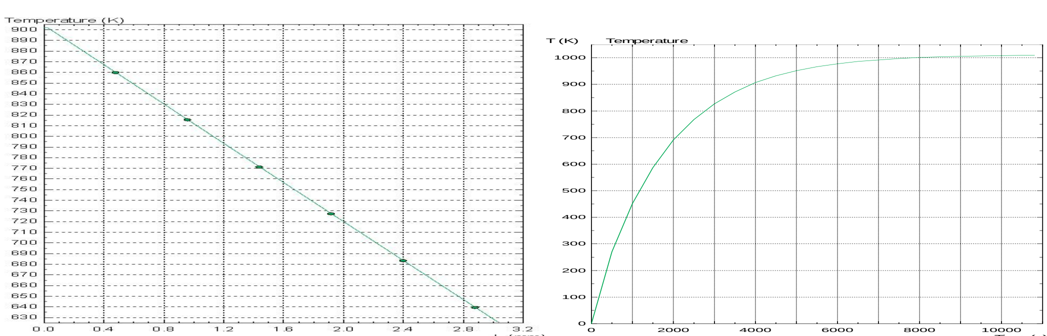


Fig. 10. a) Thermal field variation in isolation layer between points D(18,16) and E(21,16) at t = 5500s, b) Thermal field variation in isolation layer in point of coordinations F (23,14)

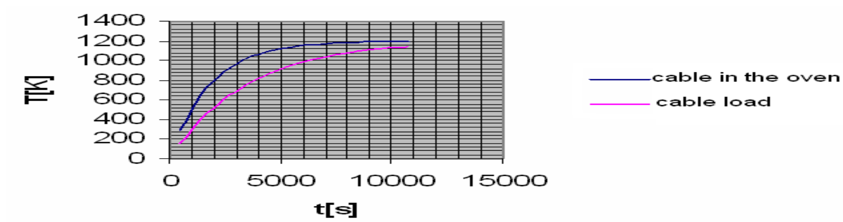


Fig. 11. Variation of thermal field in the coordinates G (18, 28) in the two analyzed situations

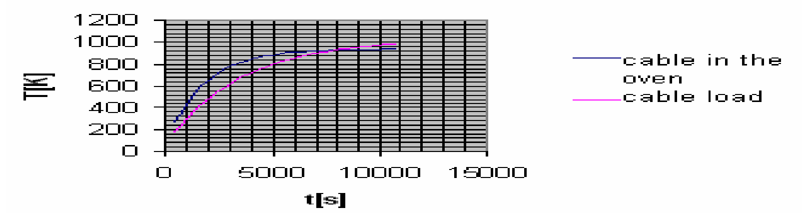


Fig. 12. Variation of thermal field in the coordinates H (20, 12) in the two analyzed situations

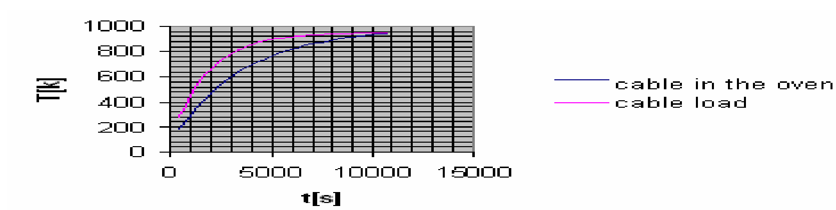


Fig. 13. Variation of thermal field in the coordinates I (19, 60) in the two analyzed situations

6. Conclusions

In this paper it was studied an algorithm concerning the numerical modeling of the inductive heating of the low voltage electrical cables. The model presented can be extended to other types of insulated cables as well as to other electrical devices constituted of heating generator metallic parts and which can worsen the insulating material properties.

This paper initiates a model of electrical cable functional tests at a reduced scale, the dimension of the cable is insignificant, requires a reduced energy consumption. The purpose of the paper is the obtaining of information about insulations, especially the new ones, in a short interval of time.

Using the results of the numerical simulation we can assimilate the effect of the inductive heating which constitutes a test at a reduced scale, with the effect of the insulation heating in normal regime or defect regime, in different functional regimes.

Once the cable subject of the heating test in the induction oven, there can be analyzed its insulation in that particular state, which corresponds to a thermal effect in normal or defect regime.

From the obtained results following the simulation results that there can be made precise assimilations between the two numerical analyzed regimes.

The numerical solution is a way to obtain precise results and to study in laboratory conditions many working regimes. Through numerical simulation is reduced the number of developing tests which constitutes a solution of reducing the designing time.

R E F E R E N C E S

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