EXAMPLE OF INDUCTION HEATING COMPUTER SIMULATION

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ABSTRACT

In this paper I describe a computer simulation example, based on the requirement of practice. Changes of electromagnetic, thermal and dilatation field distribution of turbo-generator shrink-ring are solved here. The aim is to fit the shring-ring to the body of the turbo-generator rotor using induction heating method. Computer simulations were carried out in RillFEM 2D software from RillFEM company (www.rillfem.com), which works on the principle of Finite Element Method (FEM).

KEYWORDS

Induction heating, computer simulation, shring-ring, electromagnetic field, thermal and dilatation fields, RillFEM 2D software

1. INTRODUCTION

Induction heating is often commonly used in many industrial applications. It is precisely because of its positive qualities: high density of electromagnetic energy transmitted, high reliability, low energy consumption (compared with other methods), environmentally friendly heating (heating causes no fume exhausts), high speed and easy controllability heating. For most applications, induction heating is the most appropriate and often the only way of heating.

2. PROCEDURE FOR SOLVING TECHNICAL PROBLEMS

Electrical equipment investigated, the performance of which we already have a clear idea we call the real physical system (the original). First, we abstract from its capabilities to the research problem considered immaterial and confine ourselves to its properties which we believe to be crucial. We replace (emulates) the investigated device with a simpler model, which we call the object of study. Then, using the laws of electromagnetic field theory, we mathematically describe the observed phenomena in the subject of study. In this way we get a continuous mathematical model for which they seek solutions. Subject of study and its mathematical model is usually introduced in different ways - to that of the original may therefore assign different mathematical models. In simpler cases, it will be possible to find analytical solution of the continuous mathematical model. There is often used approximate numerical solution at the present time. Then we move from continuous to discrete mathematical model which is realized on a computer. Based on the algorithm of solving the discrete model we will create a computing program, which we put into a computer, which will create a computer model. Computer models imitate (simulate) in the solved real physical system characteristics and phenomena that interest us. This process is called computer simulations. Solving electrical problems direct experimental exploration of the real physical system is difficult and costly. In contrast we perform with a computer model simulation experiments, which are operational and cost-effective.

Incorrect or inaccurate result is due to errors in any phase of the solution, such as too strong simplification in the construction of object of study, it is caused by errors in the formulation of a continuous mathematical model, there is a source of error in the numerical solution thanks to coarse

discretization of the continuous model, thanks to inappropriate choice of computational algorithm or due to errors in calculation software. It is therefore necessary to compare results, which we reached by calculation, with any credible comparable information, such as measurements on physical models or similar already completed facilities, comparing with previous experience, or maybe just the physical view of the problem solved. We say that verified obtained solutions.

Physical real system is modeled only with those objects of study, which are not in conflict with the laws of physics (we say that they are correct) but are sufficiently precise (say, they are adequate). Higher accuracy of the subject can be usually done at the cost of greater complexity, which leads to greater complicity of continuous mathematical model. Only such models have practical value for us that we are able to solve with our mathematical knowledge, or with the computer technology we have available. In compiling the mathematical model, there are then applied eccept the laws of the electromagnetic field also the experience and solver´s intuition or the art of engineering.

Let´s compare analytical and numerical solution of a mathematical model. The analytical solution is feasible only for simple objects of study and often requires high mathematical erudition of solver. Its great advantage is the general nature of the found solution, which allows greater insight into the patterns of observed phenomena - therefore has considerable prognostic cost. In contrast, computer concepts allow to work with object of study, which may have more general properties and complex structure, and thus it is more close to real physical system (so it is more accurate) than the analytical solution. The advantage of the numerical solution is that the computer work is pretty routine and the validity of the practice is universal. The disadvantage is that the results apply only to very specific cases, but not in general.

3. COMPUTER SIMULATION OF THE 200 MW TURBO-GENERATOR SHRINK-RING INDUCTION HEATING

3.1. Problem

My aim was to create a 200MW turbo-generator shrink-ring computer simulation. The aim then was to fit the shring-ring (Figure 1) to the body of the turbo-generator rotor using induction heating method. The rotor shring-ring protects coil end windings against the negative influence of centrifugal forces that act on them.

Parameters of the shrink-ring (Table 1): outer radius 561 mm, inner radius 489,5 mm, length of the shrink-ring 642 mm. The shrink-ring is made of CrMn1818 steel.

It was necessary to fulfill the following items during the heating: Required minimum radial dilation of 3 mm on the radius, maximum local temperature of 380°C, maximum temperature difference 70°C. During computer simulations, I tested the effect of the length of the inductor to change the distribution of controlled field around the shring-ring. Next I changed the following electrical and geometrical properties: size and frequency of electric harmonic alternating current flowing inductor, heating time.

The simulation results, different values of dilatation and temperature, were then compared with the theoretical assumptions and values set out in the experimental measurements.

3.2. 200MW turbo-generator shrink-ring

Table 1 – Geometric dimensions of the shring-ring

dimension	size, length [mm]
outer radius	561 mm
inner radius	489,5 mm
length of the shrink-ring	642 mm
material	nonmagnetic steel CrMn 1818

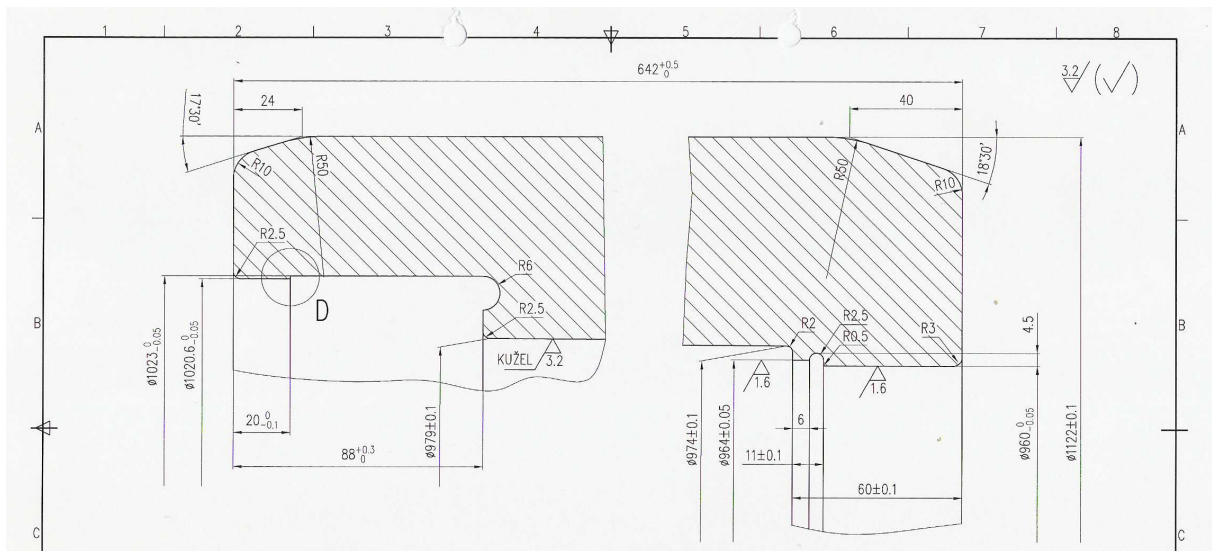Figure 1 – 200MW turbo-generator shrink-ring

Figure 2 – Technical drawing of the shrink-ring (dimensions in mm)

3.3. *Mathematical model of the inductively heated shrink-ring electromagnetic field produced by harmonic alternating current*

Differential equation:

$$\frac{\partial^2 \underline{A}}{\partial r^2} + \frac{1}{r} \cdot \frac{\partial \underline{A}}{\partial r} + \frac{\partial^2 \underline{A}}{\partial z^2} - j\omega\gamma_{el}\mu\underline{A} = -\mu\,\underline{J_{ex}}$$

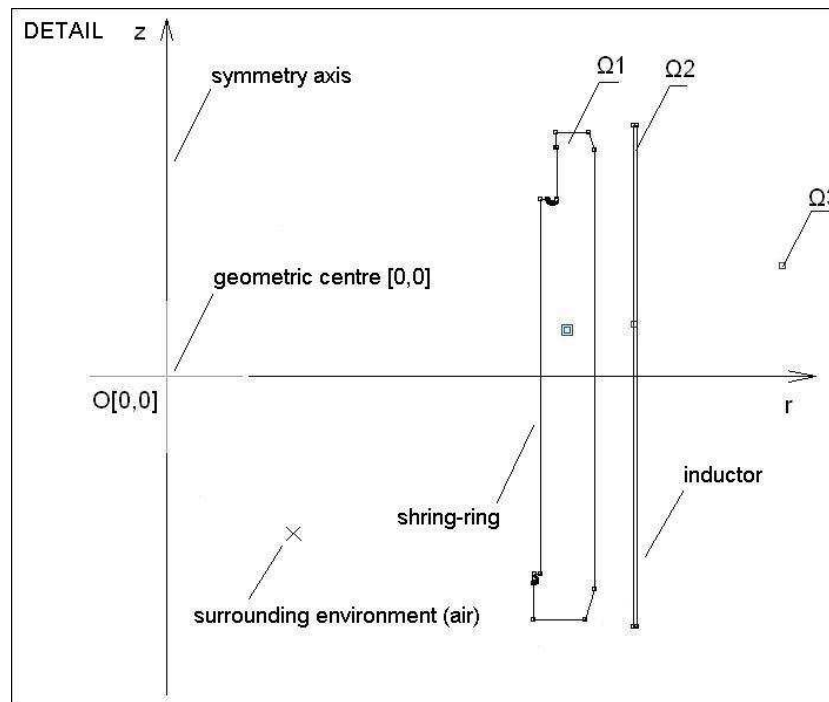|		
r	charge radius	[m]
ω	angular velocity	[s^{-1}]
γ_{el}	conductivity	[S/m]
μ	permeability	[H/m]
$\underline{J_{ex}}$	external current density phasor	[A/m^2]
$\underline{A}$	magnetic vector potencial phasor	[Wb/m]

Figure 3 – Geometric situation of the solved physical problem – the detail of the problem, the plane cut rz in program RillFEM 2D and a view of the definition area (cut without imaginary boundary)

Legend: Ω_1 …..shrink-ring area, Ω_2 …..inductor area, Ω_3 …..air area
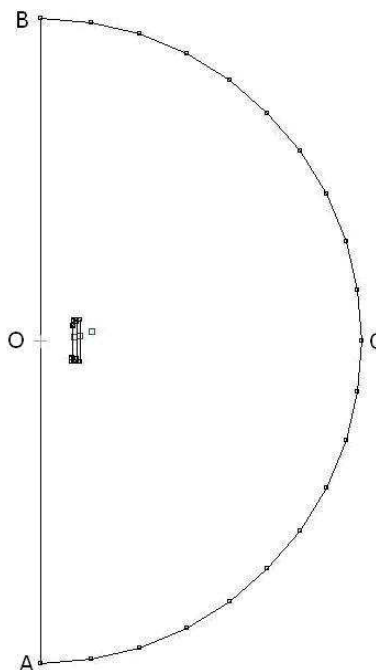
Boundary conditions

Figure 4 – Display the definition area in the program RillFEM – boundary of the investigated area (overall view)

Legend: O … center of coordinate system, AOBCA … boundary of the investigated area in the plane cut rz
AOB : A = 0   antisymmetry (Dirichlet boundary condition of the first kind)
ACB: A = 0 line of force on the fictitious boundary (Dirichlet boundary condition of the first kind)
Link: Overview of the theory basic equations for different types of fields in "7. Appendix 1".
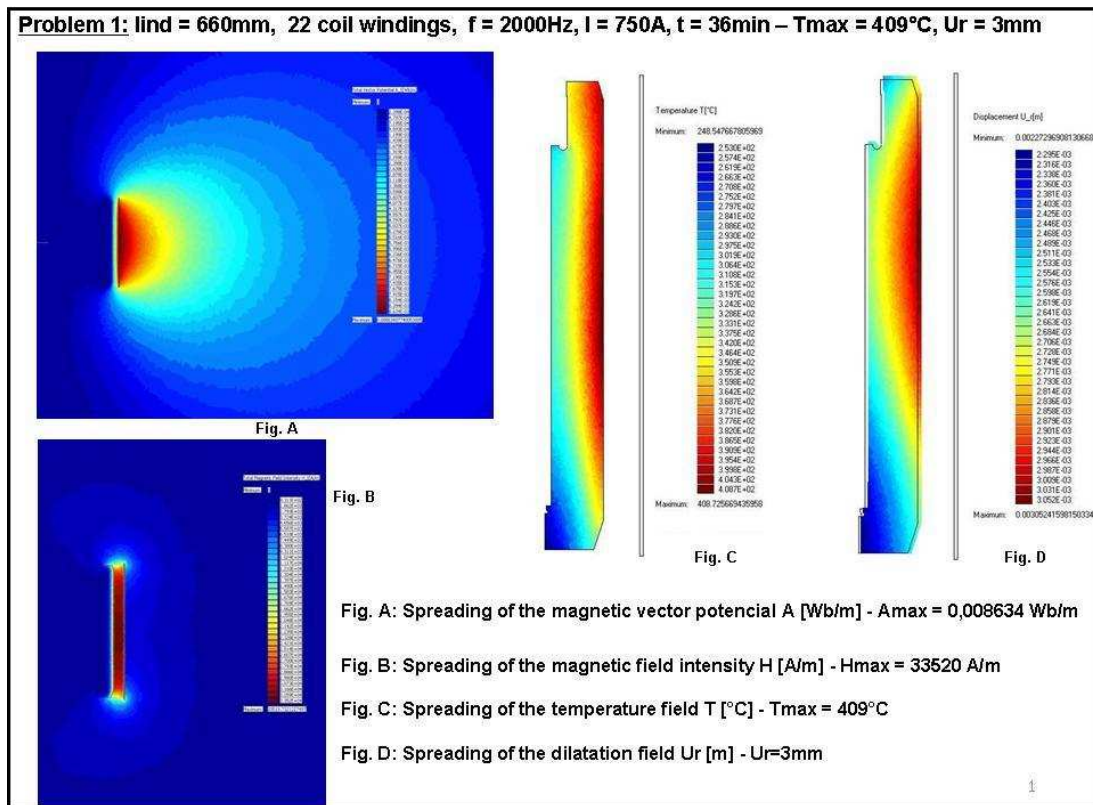
3.4.   *Examples of computer simulation results*

Figure 5 – Computer simulation result: l_{ind} =660mm, f = 2000Hz, I = 750A, t = 36min
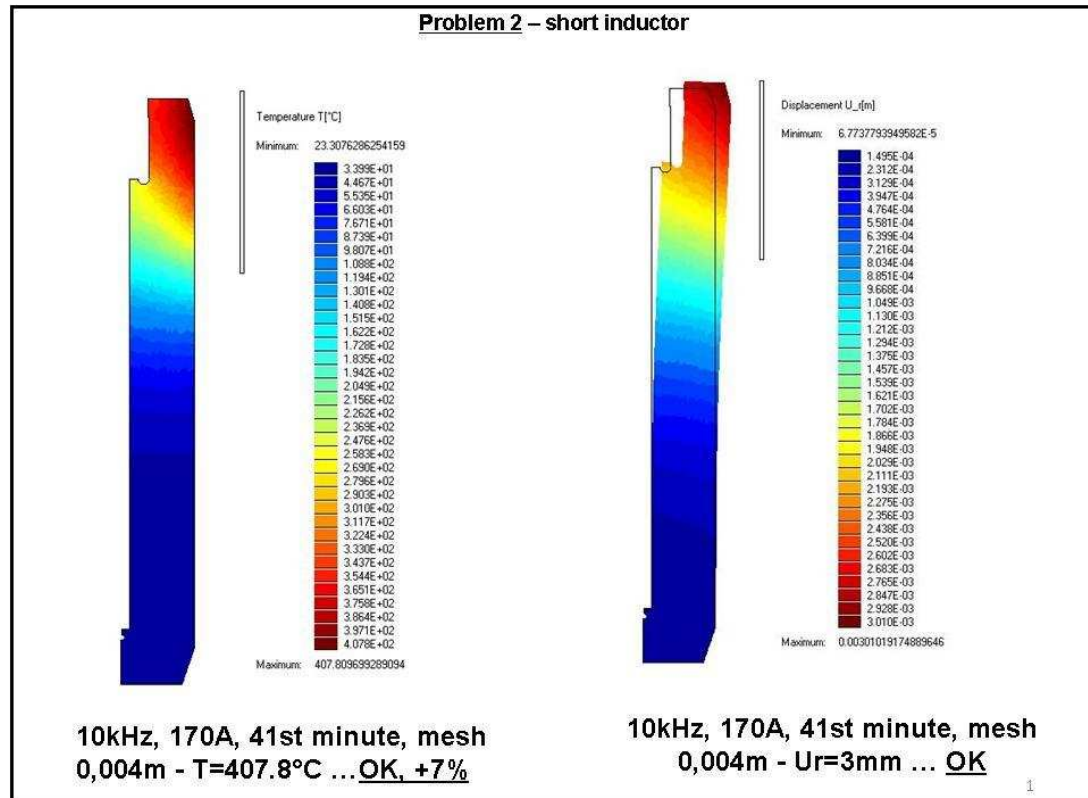
Figure 6 – Computer simulation result: l_{ind} =200mm, f = 10000Hz, I = 170A, t = 41min

4. CONCLUSIONS

Computer simulations confirmed our presumption of a minimum radial dilatation reached. Acceptable warming and the temperature difference conditions were not met. The aim of the future can be an optimal procedure for the method of heating to ensure compliance with these conditions. The example I have shown that modern computer programs are able to solve difficult complex technical problems in induction heating quite reliably. To solve the electromagnetic field can thus also advantageously solve other types of fields.

5. APPENDIX 1

Basic theory:

- **Electromagnetic field: Helmholz equation**

$$\frac{\partial^2 \underline{A}}{\partial r^2} + \frac{1}{r} \cdot \frac{\partial \underline{A}}{\partial r} + \frac{\partial^2 \underline{A}}{\partial z^2} - j\omega\gamma_{el}\mu\underline{A} = -\mu\underline{J}_{ex}$$

- **Temperature field: Fourier-Kirchhoff**

$$\frac{\partial^2 T}{\partial r^2} + \frac{1}{r} \cdot \frac{\partial T}{\partial r} + \frac{\partial^2 T}{\partial z^2} = \frac{c\rho}{\lambda} \cdot \frac{\partial T}{\partial t} + \frac{w_J}{\lambda}$$

- **Dilatation field: Lamé equation**

$$(\lambda+\mu)\mathrm{grad}(\mathrm{div}\ \boldsymbol{u})+\mu\Delta\boldsymbol{u}-(3\lambda+2\mu)\alpha T\ \mathrm{grad}T+\boldsymbol{f}=0$$

Figure 7 – Overview of the theory basic equations for different types of fields

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