Numerical modelling of cylindrical composite materials heating in dynamic modes

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Abstract. Presented paper describes the dynamic processes, which are happens during the process of creating the steel pipes with protection layer. This protection layer saves the pipes from chemical reactions on inner or outer side during their using in industry processes. The main aim of presented work is receiving of requested temperature profile in the place of connection of the steel and protection material.

1. Introduction
The receiving of composite materials is quite difficult process. Many parameter parameters must be taken into consideration during the designing phase of creating the installation. The easiest way to make some finance and time economy is using the numerical modelling of the process as a part of designing phase. It is necessary to receive requested temperatures in the workpiece, because under- and overheating of the materials will decreased the quality of the final product.

2. Numerical models and simulation algorithm
In the frame of this work it is need to receive the results of the heating process for the case, when the edge of the pipe is coming over the induction system and comes to “quasi”-steady state mode. The pipe is coming over the inductor and the heating temperature on the connection place between steel and protection material must be close to 1000 °C. The starting temperature of the process is equals to 20 °C. Underheating will not give the required connection between both materials which reduce the quality of the workpiece and overheating can damage final multilayer pipe. As it is shown in figure 1 a and 1 b the numerical models include: inductor (1), steel pipe (2), protection material (3) which is located inside the pipe in one case and outside in the second one, and thermal isolation (4) to save the inductor from the heating processes. Figure 1 shows the numerical model on 60th calculation step. Numerical simulation has been done in 2D and numerical models have cycling symmetry over Y-axis. The investigated installation has the same inductor. The difference between both numerical models consists only in the workpiece. The dimensions of the steel pipes are the same, but the protection material locates inside or outside from it. The frequency of the current in both models is equals to 1000 Hz and the current value has been chosen to receive 1000 °C ± 1% in the protection material on the time, when the process starts to be in “quasi”-steady state mode. The numerical models have been done in ANSYS® Software [1] which gives a possibility to make structural analysis on the next design steps.
The numerical models include the movement of the workpiece over the inductor and figure 2 shows the location of the edge of the workpiece relatively the inductor on different calculation steps (40th – 2-a, 50th – 2-b, 60th – 2-c and 100th – 2-d). On 100th calculation step the numerical model comes to “quasi”-steady state mode in electromagnetic and thermal calculation.

The numerical algorithm for numerical models is presented in figure 3. The presented algorithm already has been used for other tasks [2], therefore this algorithm does not need to been verified. On the first part of simulation algorithm comes the creating of electromagnetic and thermal databases for each location of the workpiece relatively the inductor. Then comes the second part of the algorithm: the electromagnetic calculation for the first calculation step. The main result of the electromagnetic calculation is Joule heat distribution in the workpiece, which is taking into account in the third part of the algorithm: thermal analysis. Besides the Joule heat generation, thermal analysis also includes temperature depended thermal properties like thermal conductivity and specific heat, and also it includes convection and radiation of induction system. Then the algorithm comes back to the second part – electromagnetic analysis. The received on previous step temperature distribution is includes to second electromagnetic calculation step, electromagnetic properties of the system have a correction to received temperature profile and starts the second electromagnetic calculation. The cycle of the algorithm is looped until last calculation step, when the system starts to be in “quasi”-steady state mode.
3. Electromagnetic analysis

As it was described earlier, the main result of electromagnetic analysis is a Joule heat distribution in the workpiece because of initial conditions for thermal calculation. The figure 4 shows the Joule heat distribution on 40th (4-a), 50th (4-b) and 60th (4-c) calculation step for the numerical model, where protection material locates inside the steel part of pipe. The view of Joule heat on 100th calculation step looks completely like on 60th calculation step and will not be presented here. On 100th calculation step only the values of Joule heat are a little bit different because of temperature depended electromagnetic properties. The maximal values of the Joule heat are presented in figure 4-b because the electromagnetic field of “free” part of the inductor has an influence to the part of the workpiece which is already located in the inductor. In figure 4 are shown only the steel parts of the workpiece because the protection material of the workpiece is sturdy against to induction frequencies.

Figure 4. Joule heat distribution in the steel during the simulation process.

In other numerical model, where the protection material locates outside from the steel, the Joule heat distribution is repeats the Joule heat distribution of the first model because of the same dimensions of the steel part of the workpiece and induction system. Only the values of Joule heat are a
little bit different because of the temperature depended electromagnetic properties of the induction system.

4. Thermal analysis

The temperature distribution in the protection material and inductor insulation of the numerical model, where protection material locates inside the steel pipe on 40th (5-a), 50th (5-b), 60th (5-c) and 100th (5-d) calculation step is presented in figure 5. It is possible to see, that on 40th calculation step the temperature is increased only for 29 °C from the staring temperature, but on the 50th step, when the edge of the workpiece is located in the middle of induction coil, the increasing is already equals to 348 °C. On 60th calculation step the value of the maximal temperature is equals to 930 °C and on 100th calculation step, when the system is already came to “quasi”-steady state mode, the value of the maximal temperature is equals to 1006 °C. The rings of cold temperature in thermal insulation on last calculation steps are coming from boundary conditions. Induction coils are cooling down by water and have temperature 20 °C, but the thermal insulation is heating up from convection and radiation processes, therefore maximal temperature of thermal insulation is equals to 775 °C. It is possible to see in figure 6-a. The temperature distribution in this system on last calculation step is shown in figure 6-b. The maximal temperature in complete workpiece is 1032 °C what is on 26 °C more than in the protection material, but maximal temperature 1000 °C ± 1% must be only in the protection material.

Figure 5. Temperature distribution in the protection material of the model, where this material is located inside the steel pipe, during the heating process.

Figure 7 accordingly shows the temperature distribution in the protection material and in inductor insulation on 40th, 50th, 60th and 100th calculation step in the model, where protection material locates outside the steel part of the workpiece. The maximal values of temperatures are higher than in previous case. On 40th calculation step the maximal temperature is equals to 66 °C, what is for 17 °C more than in previous case. The maximal temperature of 50th calculation step is 578 °C, what is for 210 °C more than in previous case. On 60th calculation step the maximal temperature in the workpiece is for 24 °C more than in previous case and equals to 954 °C. But on the last calculation step the maximal value of the temperature in protection material is equals to 1007 °C, what coincide to initial task of the simulation.
Thermal distribution in thermal insulation (8-a) and in all system of induction composite pipe heating system in “quasi”-steady state mode (8-b) with outer protection material are shown in figure 8. The thermal insulation is not heated too much like in previous case because the outer protection material is heated most by thermal conductivity from steel pipe and has other thermal properties. The thermal isolation has been heated only for 93 °C. The maximal temperature in the steel pipe is equals to 1033 °C but the protection material has been heated to required temperature.

The dynamics of maximal temperature in the protection material (dash curves) and in the steel pipe (permanent curves) for the numerical models where protection material locates inside (grey curves) and outside (black curves) during the induction heating simulation is locates in the figure 9. In case, where protection material locates outside the steel pipe, the heating of both materials is happens more similar till the moment, when edge of the workpiece is coming out from the inductor. In other case, the heating of steel pipe comes faster.
5. Conclusions and outlooks
The developed dynamic numerical models have been done. This gives more information about the dynamics of the composite tube heating. The next work is directed to simulate the numerical systems with variable value of the current to make overheating of the protection material much smaller in the time, when edge of the workpiece is coming during the induction coils. But received results are already extending to using them in design phase of induction heating installation for receiving the composite pipes.

References
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