Didier Werke AG
InduCer Group
Abraham Lincoln Str. 1
65 189 Wiesbaden
Germany

E-mail contact: Jivan.Kapoor@RHI-AG.com

Introduction:

At Didiers the so called IndCer (**Ind**uctively Heated **Cer**amics) - project is dedicated to the development of a new technology for applications in steel production. In steel plants one of the major problems is the steel flow control when teeming out of a metallurgical vessel, e.g. a Tundish. Due to the danger of steel freezing in tap hole nozzles one would like to be able to heat such nozzles as mounted in the wall and during casting. This is impossible to do using conventional methods like gas burners etc. An inductively heated - i.e. electrically conducting - ceramic nozzle would be a good solution for that problem. This basic idea is a patent owned by the Didier Werke AG. In the following an illustrative example for the InduCer-technology will be reported.

Example:

A rather specific application of the InduCer-technology is the BGH.pbm given here, where we have heated up the nozzle of a Tundish attached to a mould of a horizontal steel caster using an air-cooled induction coil. To be able to understand the example it is only important to know that steel flows from the right side through the nozzle into the mould where it solidifies building a strand which is continuously drawn out of the caster. From the simulation point of view it was our task to learn as much as possible of what is going on in this experimental set-up with the aid of a FEM tool. We decided to start with Quickfield for simplicity reasons and moderate costs.

In general, InduCer set-ups always consist of a middle frequency generator feeding the necessary electric power into a resonance circuit build from the induction coil, a parallel capacitor, and some connecting lines („cable“). To lay out a whole InduCer-system is a rather complex problem. For example, one needs to have information about the

i) heat source distribution and resulting temperature field in e.g. the heated ceramic part

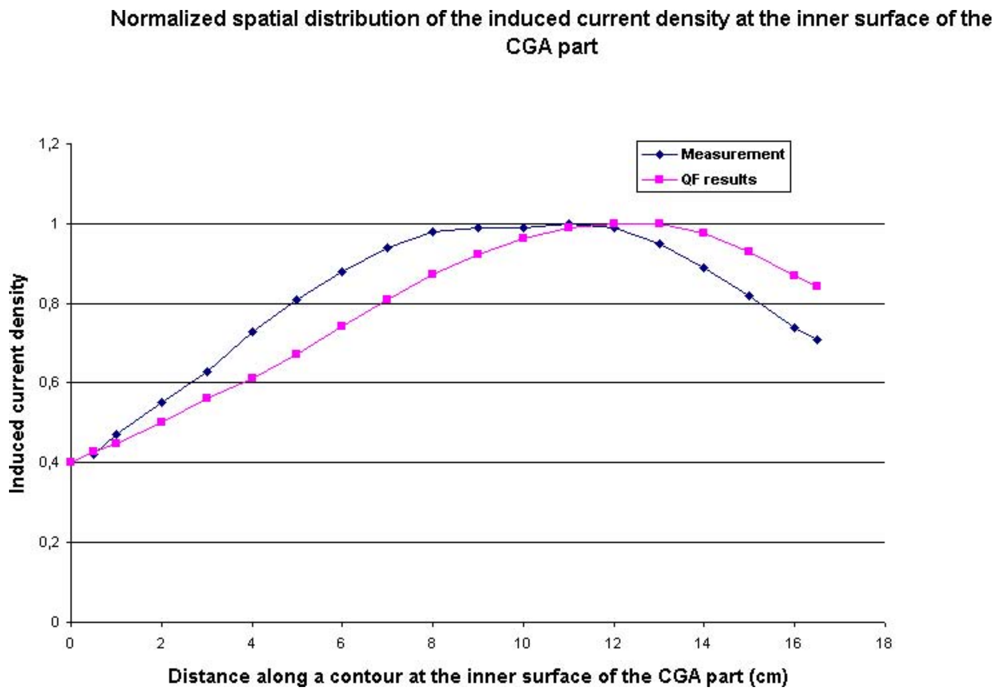
ii) electrical impedance of the coil (Z_{COIL}) and Stromschiene (Z_{SS}) in order to tune and adapt the resonance-circuit to the generator properly

iii) efficiency factor of the induction process

iv) air-cooling requirements and efficiency etc.

Once having access to this data one is able the find an optimum lay-out. Quickfield can provide a major part of the necessary information. In combination with additional self-written programs (e.g. in MS-Excel) to cover some physics not directly tractable to Quickfield (see below) it is possible to achieve a quite accurate simulation of the complex behaviour of our set-ups. Obviously one is free to study different geometric designs qualitatively. Moreover, also quantitative studies can be carried out and give valuable results. For example, it is necessary to determine the optimum number of coil turns in order to have a maximum transferred power from the generator to the induction coil. For doing this only the cable.pbm and BGHel.pbm for a one-turn-coil covering the desired range of the final coil need to be solved. The optimum number of coil turns can then be determined by a“resonance circuit“-program using only the Quickfield results for the total generated heat power, the total field energy and the driving current (or equivalently Z_{SS} and Z_{COIL}) as input parameters. In BGHel.pbm N_{OPT} has been determined to be around 7.

Generally, a comparison of Quickfield-results with experimental data is very satisfying. For example the inductance of a free standing coil usually compares within 10% with the measurement, whereas the real part of the impedance even can be estimated to be by far more accurate (A systematic error in inductance seemingly originates from the use of boundary conditions for vector potential A=0 at an artificially finite radius). Experimental measurements for heat source distributions also agreed well with the QuickField result (see Fig.1).



In a next step one can also try to obtain information about the thermal behaviour of the set-up in calculating a thermal problem (BGHth.pbm). One might even attempt to simulate the cooling effect of the air flow through the hollow copper-coil in this context. While the first task is straight forward the latter can be done only approximately on the basis of engineering methods giving appropriate values for an convection cooling condition at the coil/air-cool boundary. Again additional programs have been designed for that purpose. The accordingly calculated values for the air flow compared well with the measurements and the calculated alpha-coefficient of 1200 W/m^2K at the inner coil-surface seems reasonable. Seemingly, alpha stays more or less constant independent of the state of the gas stream. Quickfield now allows to study the heat transfer from the coil to the air flow - and hence the cooling-efficiency - in an iterative process. Beginning with an initial temperature for the air-flow one calculates the temperature increase from one to the next coil turn produced by the transferred heat as obtained from the “first iteration step“ Quickfield solution. In the next step one uses the new set of air-temperature values, recalculates, and again determines the temperatures for next iteration step and so on. This method converges quick and leads to a final temperature of around 460 K or 545 K, respectively for the out coming air flow, as can be seen in the final result-file given here. (In the example there are two cooling lines consisting of coil-turn 1 to 4 and coil-turn 5 to 7.) Of course, this method can not be expected to be highly accurate due to the neglect of some important physical phenomena, like involved in e.g. the more complex fluid dynamics, the expansion of the air flow, and the T-dependent decrease of the copper-coils conductivity (Though a part of this could be treated with Quickfield with more work). However, in this way a valuable first guess can be obtained with Quickfield, moreover, as the gross features of the temperature field solution do not depend crucially on the exact induction coil temperature.

Summary:

A short - by far not complete - overview of Quickfield´s capabilities to simulate InduCer-devices has been given. It is Quickfield´s great advantage to offer a very efficient approach to simulate a certain class of 1D/2D-FEM-problems. In comparison to other perhaps more powerful „state of the art“ software the handling of the program can be learned easily even by non-expert users. This made Quickfield a most valuable tool for our purposes, although it could not provide a full “ab initio“ simulation of all physical effects under consideration.