International Scientific Colloquium
Modelling for Electromagnetic Processing
Hannover, October 27-29, 2008

Thermal Modeling of an Induction Coil; Model vs Experiment

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Abstract

In the search for a better understanding of the thermal stresses in an induction coil a model combining the electromagnetic, fluid dynamic and thermal aspects of the induction coil was developed. Experimental validation was conducted, but temperature measurement in a critical area of the coil showed an unexpected decrease. By changing the position of thermo-graphic camera a better view of the coil was obtained. The new improved measurement shows that the temperature decrease is a measurement problem and supports the temperature estimates of the model.

Introduction

In the investigation of the working conditions of an induction heating coil, the determination of the temperature distribution of the coil is important. The temperature at the surface of the coil can be measured, for instance optically, but the temperature inside the copper of the coil is far from trivial to measure. A numerical model of the temperature is needed that incorporates the electromagnetic, heat transfer, and the fluid dynamic aspects of the water cooled conductor of the induction heating coil. The investigated geometry in the paper is a near plane symmetric hairpin type coil. The geometry is investigated at a cross section away from the ends of the coil, allowing negligence of the end effects, so the electromagnetic part of the model can be reduced to a 2D plane symmetric model. The CFD (Computational Fluid Dynamics) part of the problem is 3D since the flow profile develops along the cooling channel of the coil. The model presented in our previous paper [4] gives acceptable results, but the temperature measured has a roll off towards the edge of the coil not shown in the model. The purpose of the measurements in this paper is to investigate if this is a measurement problem or an unexpected dip in actual temperature.

The Numerical Model

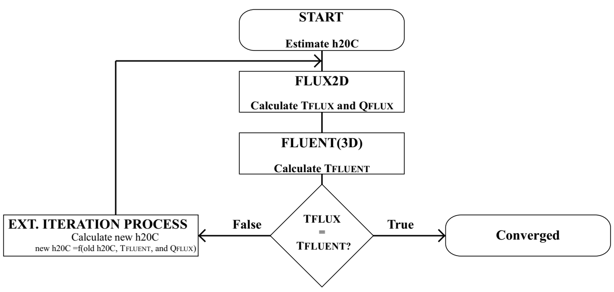

Fig. 1. Iteration process.

The numerical model is based on magneto thermal calculations done with the finite element software Flux2D and fluid dynamic calculations done with Fluent. The two models are combined through external scripts to form an iterative process as shown in Fig. 1. The model is based on estimates of heat transfer coefficients that are iteratively improved by calculating the temperatures by looking at Joule losses in Flux2D and heat transfer to the water in Fluent. When the difference in temperature in the two models are sufficiently small, the combined model is considered converged. Further description of the model and its use can be found in [1] and [2].

The Experimental Setup

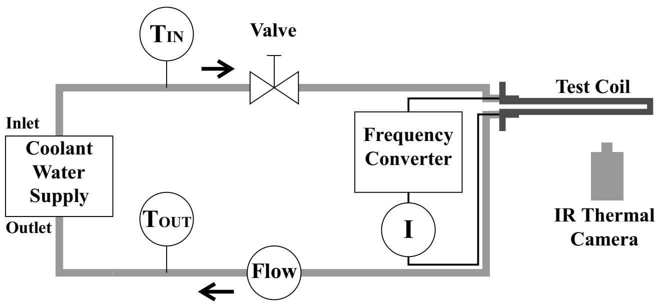

Fig. 2. Experimental setup. Gray lines are coolant and black lines electricity.

The experimental setup is basically the same as the one used in [1]. The experiment was set up in an induction hardening machine. Coil electric current and coolant flow were adjustable and coolant temperature in and out, coolant flow and electric current were measured. In addition the surface temperature of the coil conductor was measured with a thermographic camera.

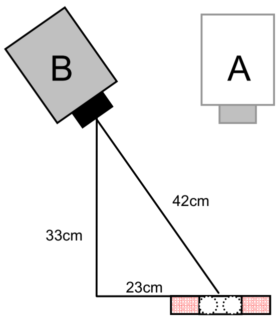

Fig. 3. Thermographic camera positions.
A-Old B-New

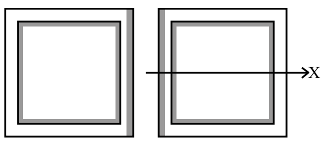

Figure 4. Cross section of conductors with heating and cooling zones in grey.

For the thermographic camera to measure the correct temperature the emissivity of the test object has to be correct, the surrounding temperature has to be known, and the camera has to be placed normally to the surface of the test object. To improve the emissivity the coil was painted with a matte, black paint, hot objects in the surrounding of the test setup were removed, but placing the camera normally to a curved surface as the coil tube is not possible. It must be expected that the measurements will be less accurate where the measured surface is at a steep angle. The highest temperature of the coil conductor is at the place nearest the other the parallel conductor. At this point (when measuring position A) the thermographic camera is located tangential to the measured surface. To improve this, the camera was moved to position B as shown in Fig. 3. As seen in Fig. 5, the measured temperature (MEP08-E-H29) at the leftmost point (x = 1 mm in Fig. 4) is now closer to the numerical value and the roll-off is less prominent.

There is still an error as we traverse over the coil. The difference between the measured value and the calculated decreases until a minimum difference is reached at $4 < x < 5$ mm. This is the area where the camera is placed perpendicularly to the coil surface. The measurement labeled ‘T-Exp-C-34-4.9’ is taken with a camera positioned straight above the tube. This camera is of another type and does not seem to have this improved accuracy when measuring perpendicularly on the coil.

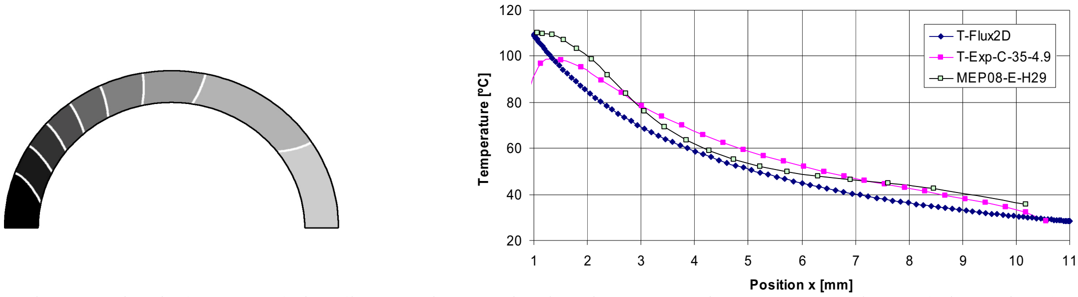

Fig. 5. The left part of the figure shows the isotherm on the cross section of the tube (30 to 100 °C in steps of 10 °C from right to left). The graph shows the temperature on the upper surface of the tube as a function of position x; Numerical and experimental with camera straight above coil and with camera at an angle sideways.

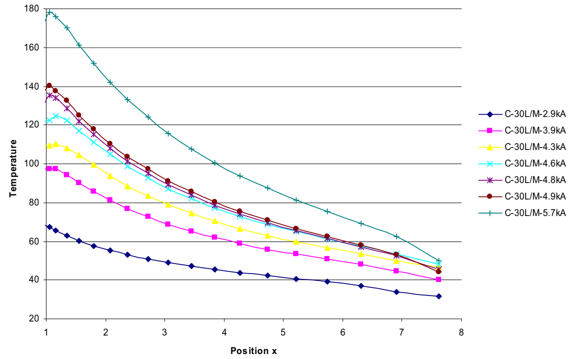

Fig. 6. Temperature meassurements for 30 l/min over a range of currents

New measurements of higher accuracy in the region between the coil conductors were possible with this new setup as shown in Fig. 6.

Conclusions

The new thermographic camera angle shows that the estimates of the model presented in [4] are correct in not predicting a decrease in temperature at the edge of the coil conductor. This effect in the measurements is due to temperature measurement taken perpendicularly to the coil surface.

References

[1] Svendsen, K, Hagen, S. T., Melaaen, M. C.: *Temperature distribution in selected cross sections of induction heating coils*. Proceedings of the International Symposium on Heating by Electromagnetic Sources, Padova, 2007, pp. 357-364

[2] Svendsen, K., Hagen, S.T.; *Thermo-Mechanical Fatigue Life Estimation of Induction Coils*, Submitted to the International Scientific Colloquium of Modelling for Electromagnetic Processing, Hannover, 2008

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