Resistive Losses in a 3-D Coil

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Introduction:
Inductive sensors are widely applied in the industrial field. In this example it is part of the measuring principle to determine the losses in the sensor coil. With *Finite Element Analysis*, it is easy to calculate exactly axisymmetric coils in 2d, taking skin and proximity effects into account .
If the coil is modeled in 3 dimensions, the small distances of a few microns between the single wires lead to enormous computational efforts. The full resolved 3d model contains about 50 Mio. mesh-elements. (Made with default *Physics-Controlled Mesh.* The *swept mesh* feature may reduce the number of elements).
The meshed 2d model (fig.2) has about 5'000 elements, the "multi-turn coil" 3d model (fig.1) has 20'000 elements. To avoid time-consuming calculations it is obviously better to split the simulation into two steps.
This presentation shows how to split the coil into a 2d- and a 3d model und how to compose the calculated losses.

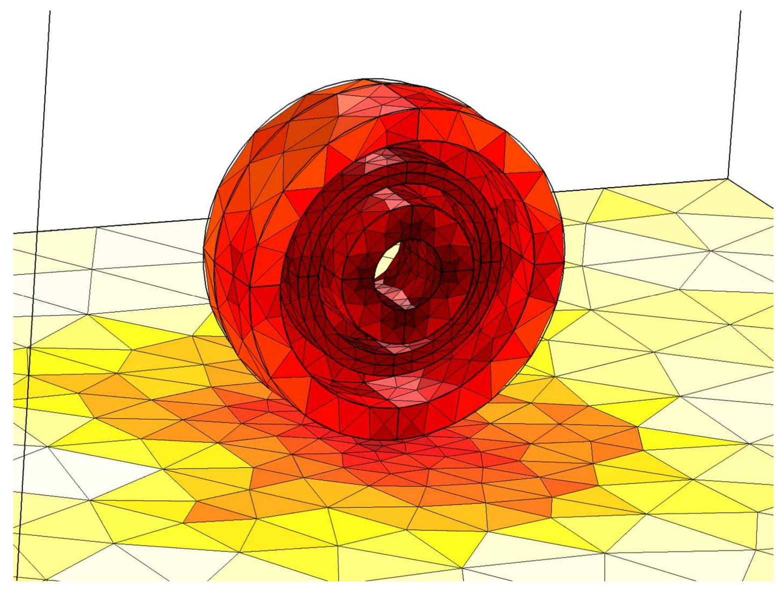

Figure 1. "multi-turn coil" on a steel plate

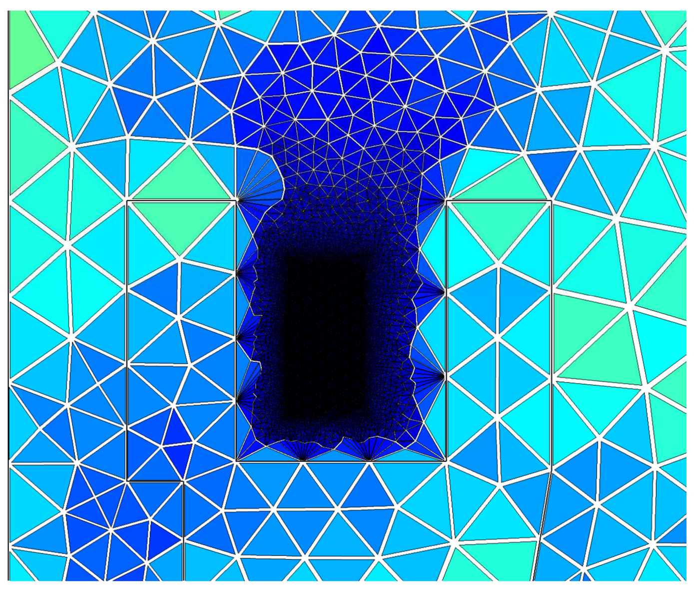

Figure 2. 2d "single turn coil"

Computational Methods:

- AC-DC Modul with "*Magnetic Fields*" interface was used (calculating the magnetic vector potential)
- Skin, proximity-effects and resistive effects have been calculated using a *"Single Turn Coil Model"* with the 2d axisymmetric model.
- The losses inside the steel plate have been determined with a 3d model. The coil has been simplified with the *"Multi-Turn-Coil"–model*, without dissolving the single wires. The steel plate is modeled with the *"Impedance Boundary Condition"*. Doing so, there's no need for dissolving the skin depth of the plate with volume elements.
- In a last step the losses in the steel plate have been transformed into a coil resistance and added to the coil resistance caused by resistive-, skin- and proximity-losses.
- Remark: As shown in figure 6, the resistances can only be added directly when the electromagnetic properties of the plate do not change the inductance of the coil significantly. Otherwise, an iterative procedure has to be applied.

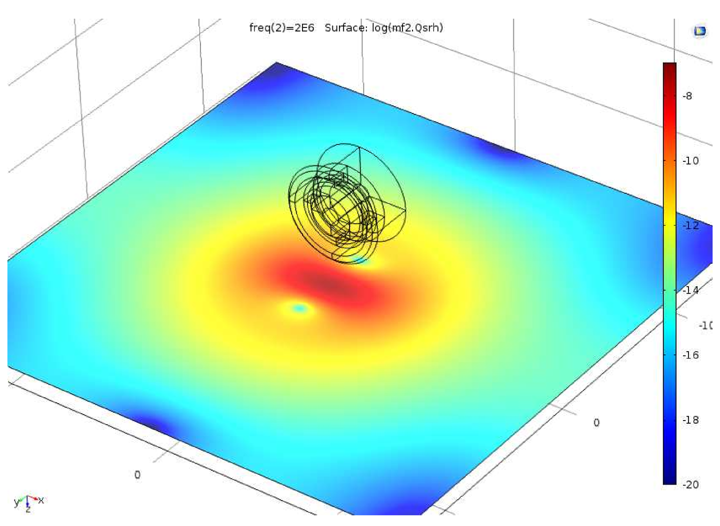

Figure 3. resistive losses in the plate

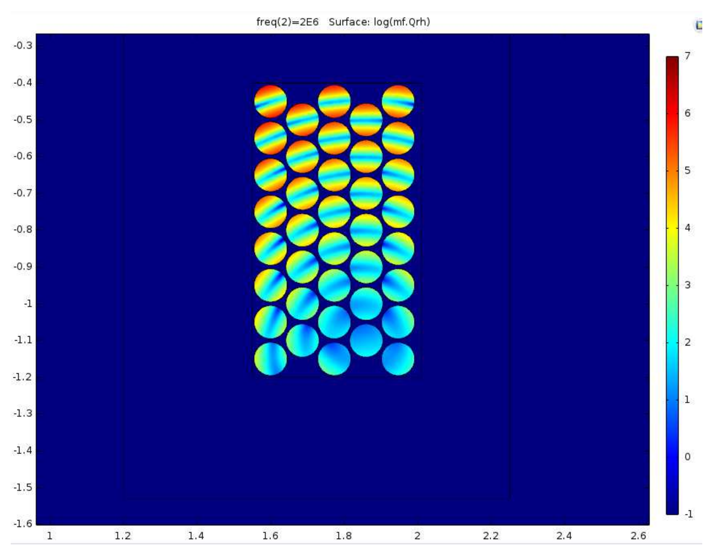

Figure 4. resistive losses in the wire

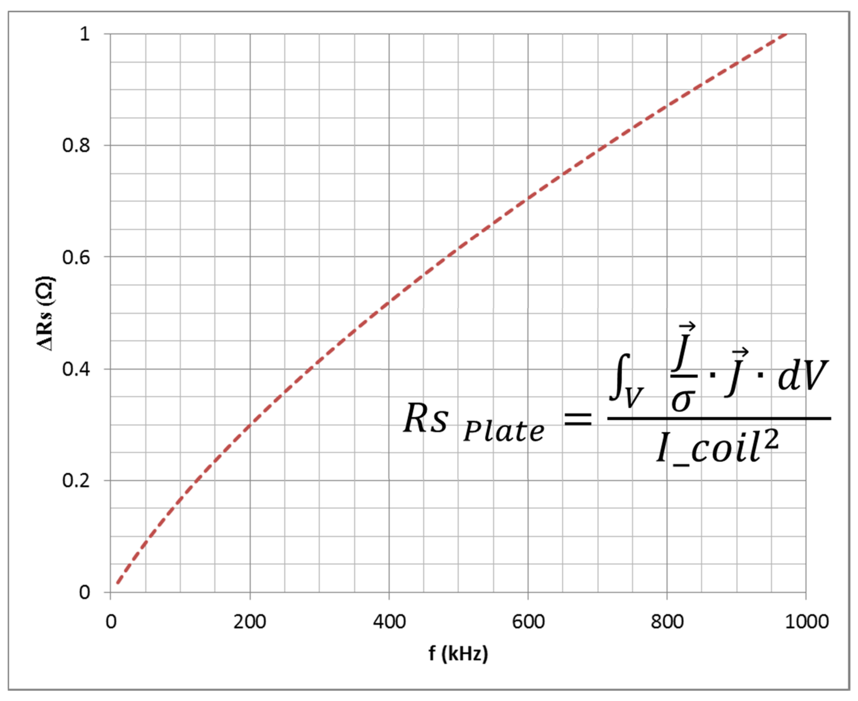

Figure 5. coil resistance, caused by the plate

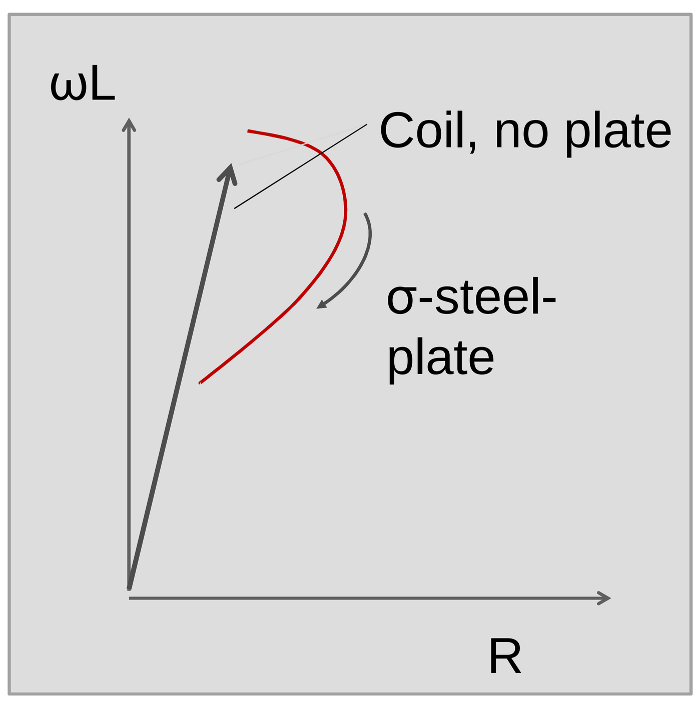

Figure 6. locus

Results:
The 2d-solution (fig.7) shows the effect of the magnetic field inside the copper wires. Additional to the external current feed, there are induced eddy currents, causing resistive losses.

2d-simulations:

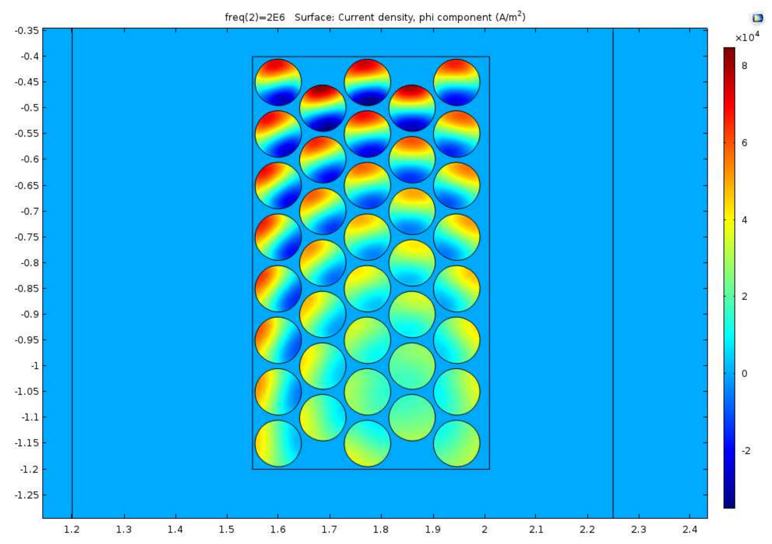

Figure 7. Proximity Effect (current density)

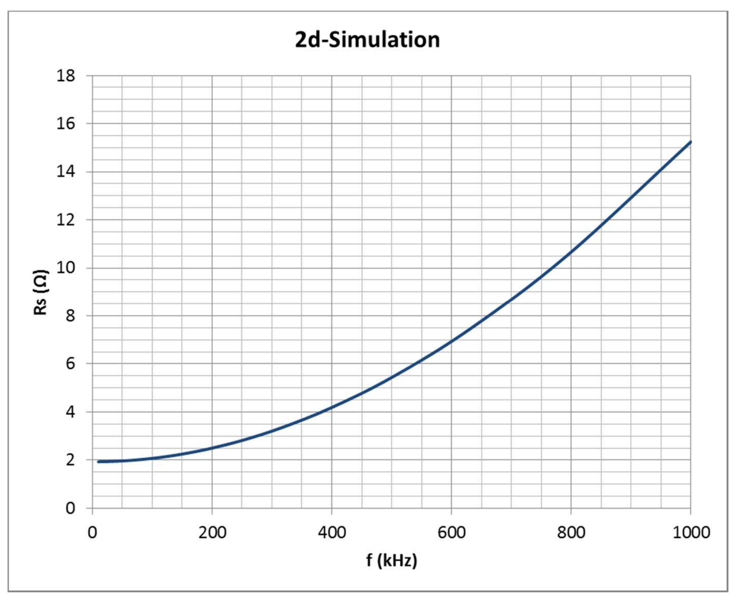

Figure 8. Coil resistance

3d-simulations:

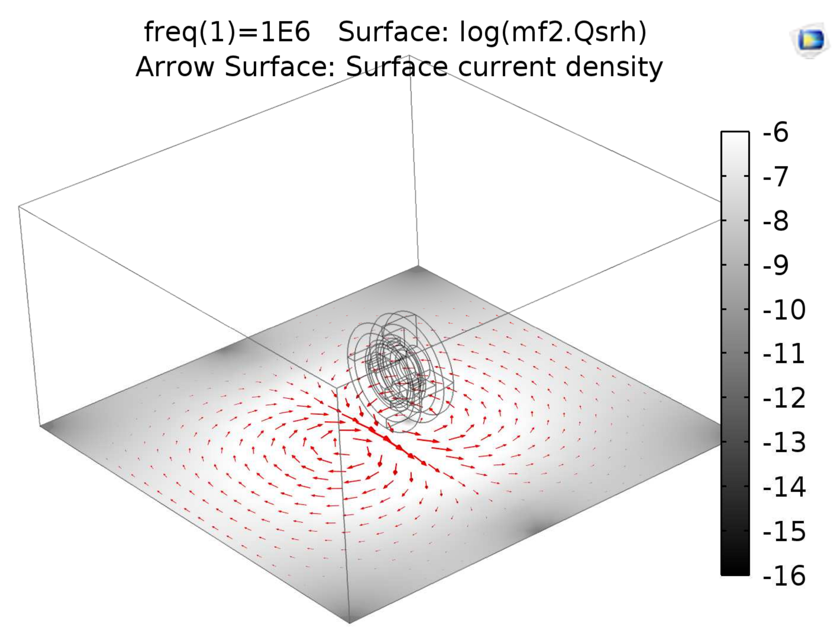

Figure 9. Induced current

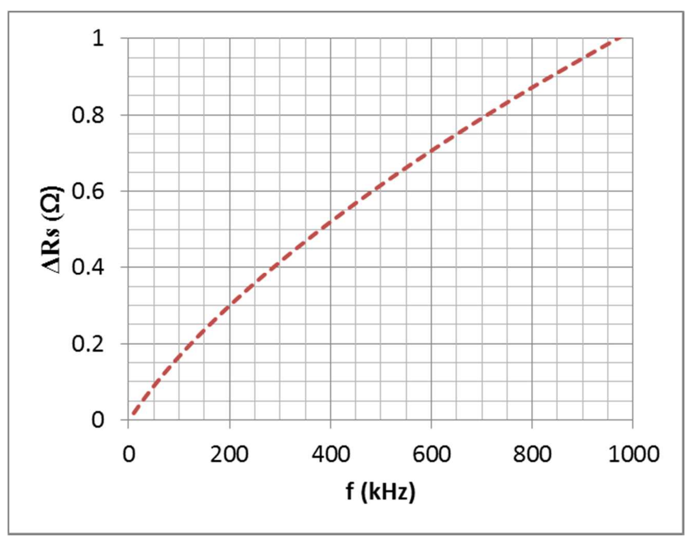

Figure 10. Expected increase of coil resistance

Measurement and Comparison:

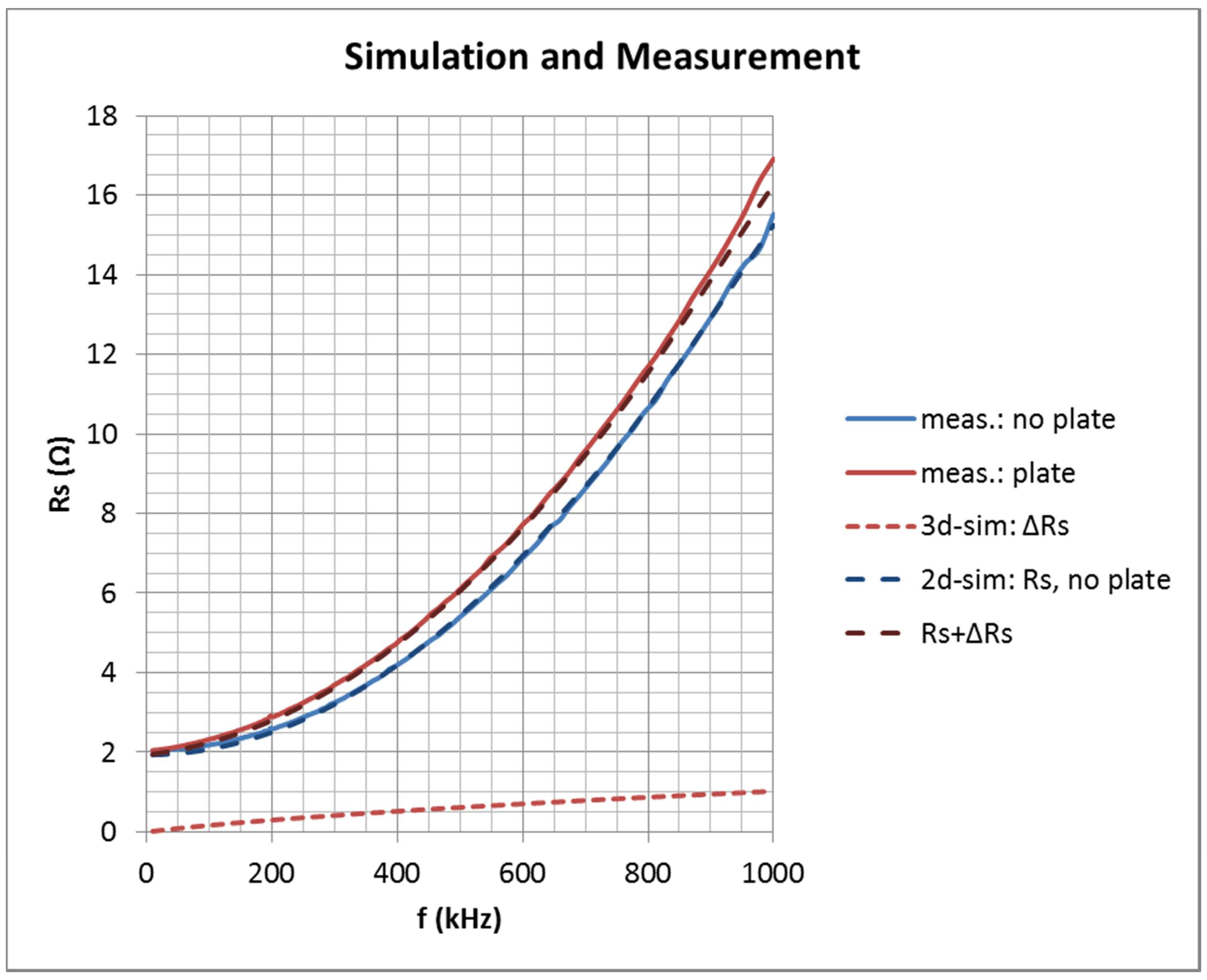

Figure 11. Coil Resistance

Conclusions:

- Thanks to numerical simulations, difficult installation situations can be tested first in theory.
- The 2d-3d method allows the calculation of 3d models in a few minutes (2.5 min for the 3d-model and 30 s for the 2d-model)
- The simulation and the measurement matches very good.
- At higher frequencies capacitive effects should be taken into account.

References:

1. Stroppe, Schiebold, Wirbelstrom Materialprüfung, p.48 (2011)
2. Prof. Dr. J. Biela, Skriptum: Wirbelstromverluste in Wicklungen induktiver Bauelemente, p.13 (2012)