Methoden zur Dimensionsreduktion und zum Lösen von Multiskalenproblemen in elektrischen Systemen

Dimension reduction methods for solving multiscale problems in electric systems

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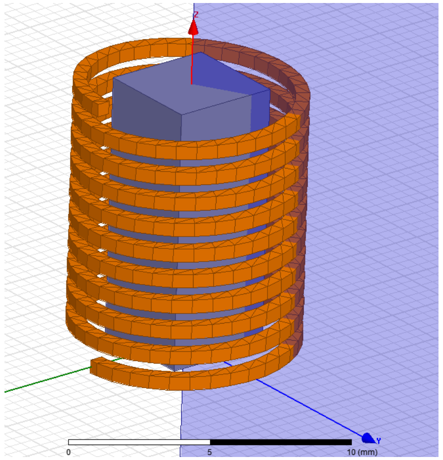
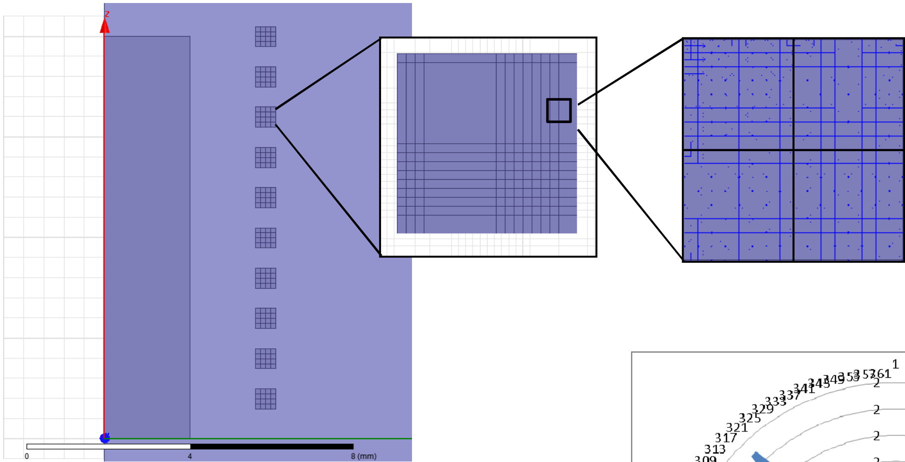
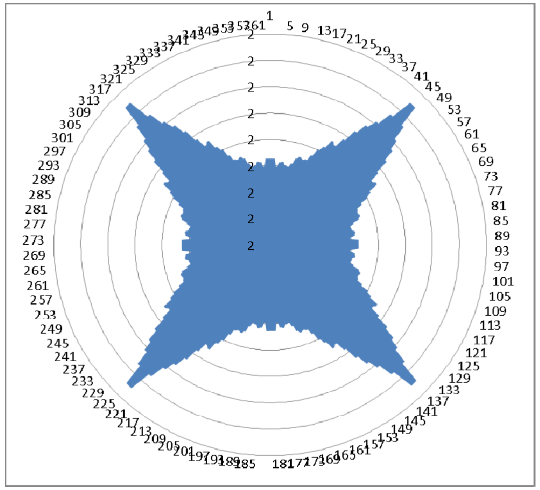




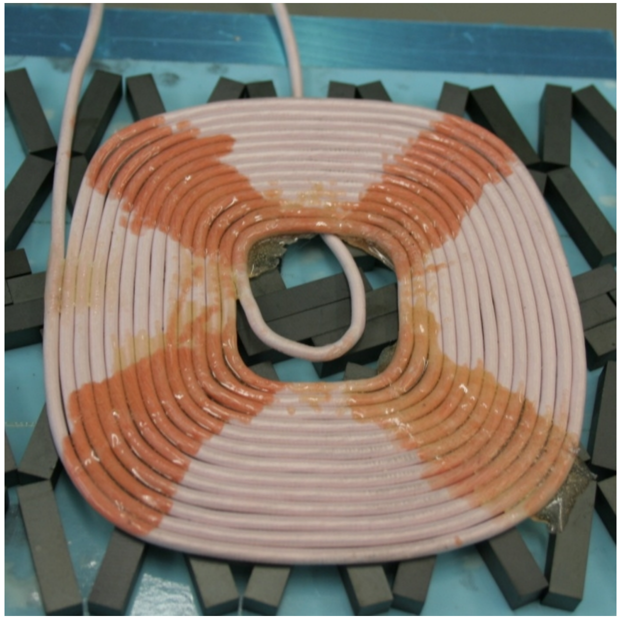


The Problem

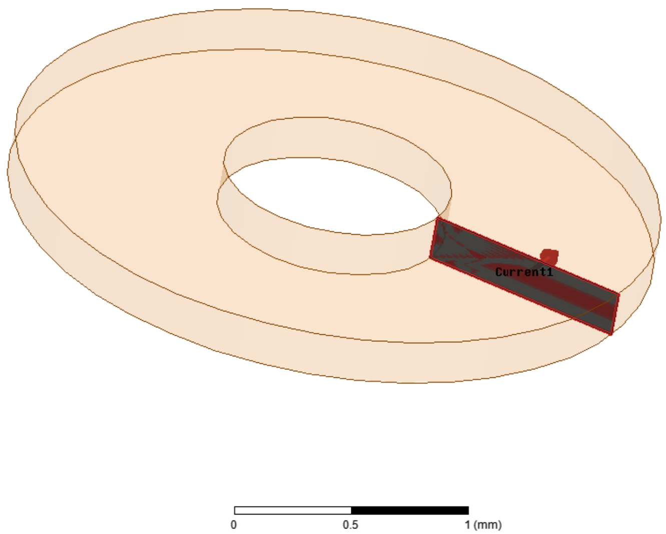
Many electromagnetic effects can **not** be described or even resolved by using standard simulation methods.

In the following slides we consider a coil as an example:

Reality



Simulation
(simplified geometry)



Simplified simulation geometries

Advantage:

- Very quick mesh generation and calculation
- Very good approximation of the external effects (field distribution, coupling)

Disadvantages:

- The inner details are not taken into consideration in the simulation:
  - e.g. different distances between windings
  - strands in the litz wire
- Inhomogeneous external fields

à Determination of the total resistance (skin and proximity) is not possible

Method

Even very fine CAD geometries can **not** resolve all the separate strands in a litz wire – in addition calculation in 3D would be impossible due to the huge amount of memory needed.

8 elements in the cross-section of each strand (0.1 mm) for 200 strands of litz wire would yield more than 1.5 10^6 elements for a piece of 10 cm length.

Approach:

- usage of (partial) symmetries
- reduction of 3D geometries to a number of 2D cuts
- implementation of detailed structures (e.g. 200 strands in a wire) in the 2D geometries
- summation of the 2D results to form a complete (representative) result for the whole 3D geometry

SLICER - procedure

A program, called SLICER, developed in our institute, enables the calculation of all ohmic losses – including skin and proximity losses - in complex 3D geometries by use of Maxwell3D.

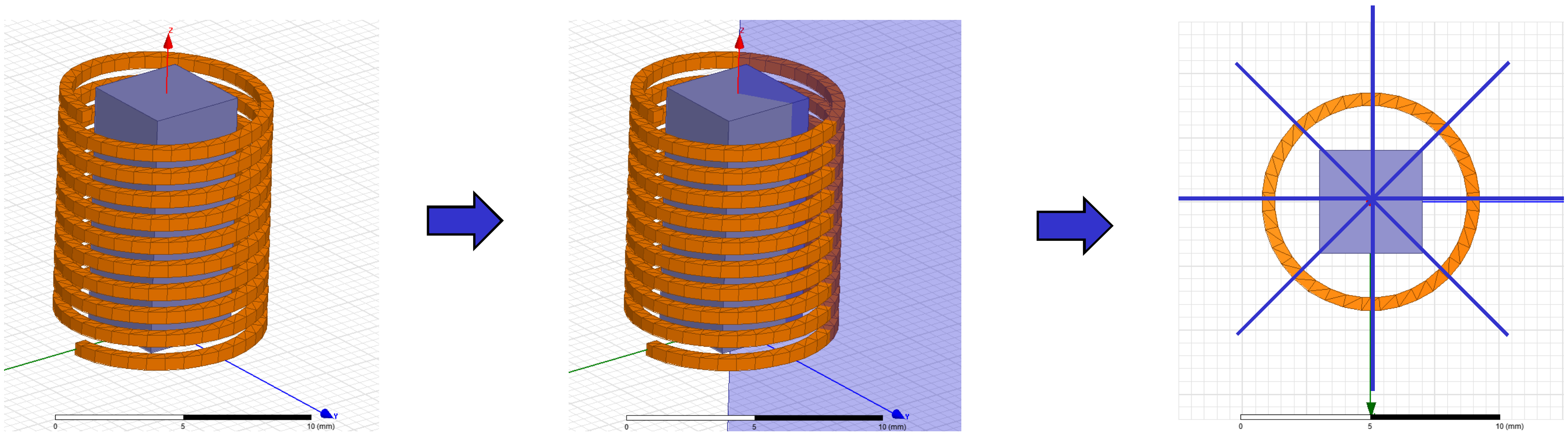
SLICER is a control script, which autonomously takes care of

- geometry operations (3D **à** 2D)
- implementation of the sub-structures (e.g. strands)
- calculation of the field distribution and losses in the 2D geometry
- adaptive addition of extra cuts as needed
- display and plot of the results in Excel

The method on which our program is based, is not limited to Maxwell3D.

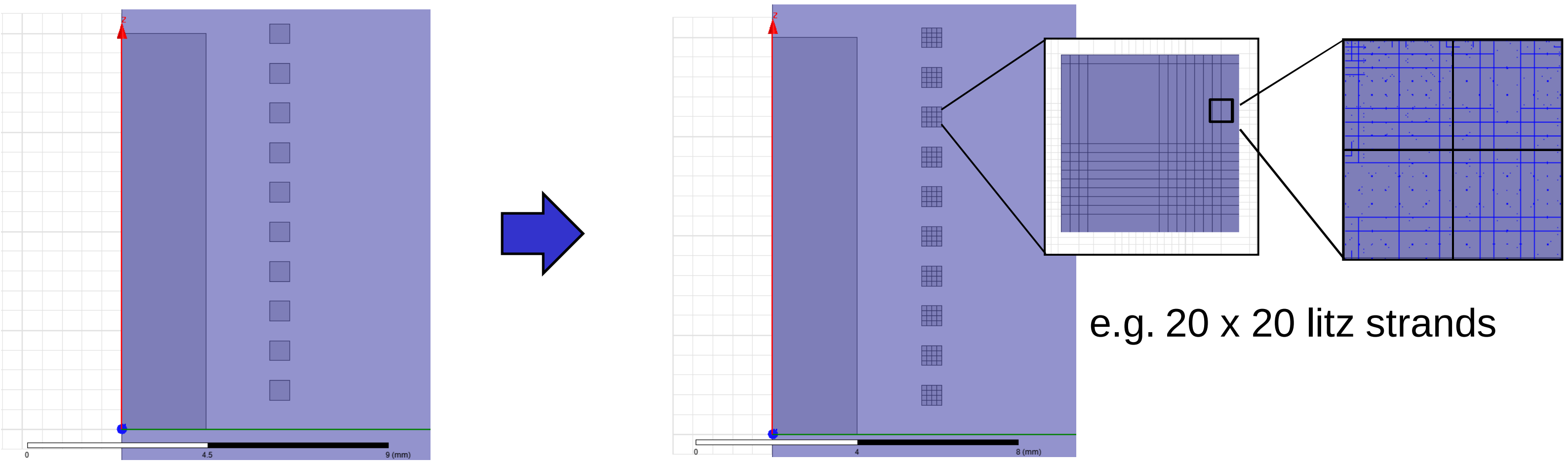
Geometry operations

- import of the 3D geometry in Maxwell3D
- usage of material prefixes for automatic assignment of material parameters (e.g. cu_coil, fe_core, pvc_housing, …)
- start of initial 2D cuts with fixed angles (e.g. 1°-3°)



Implementation of substructures and calculation

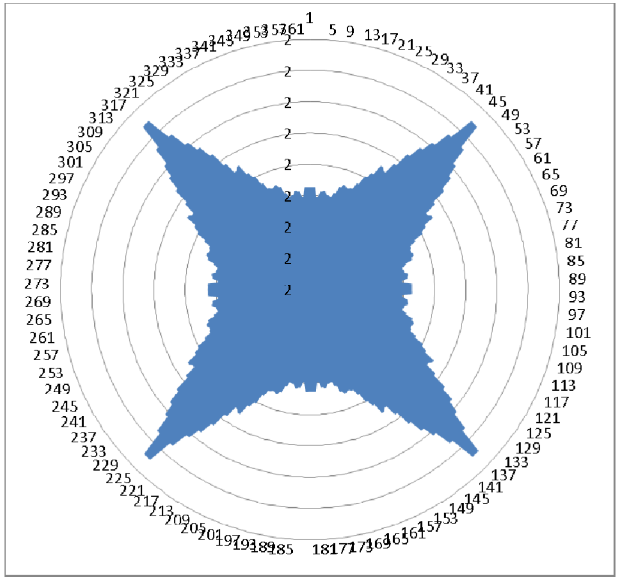
- implementation of sub-structures in the 2D geometry
- all parameters are controlled by SLICER: amount, positions and profile of the strands
- automatic definition of boundary conditions (current, grid refinements, external fields, etc.)
- calculation of the current/field distribution (solver: eddy current)
- export of losses to separate files

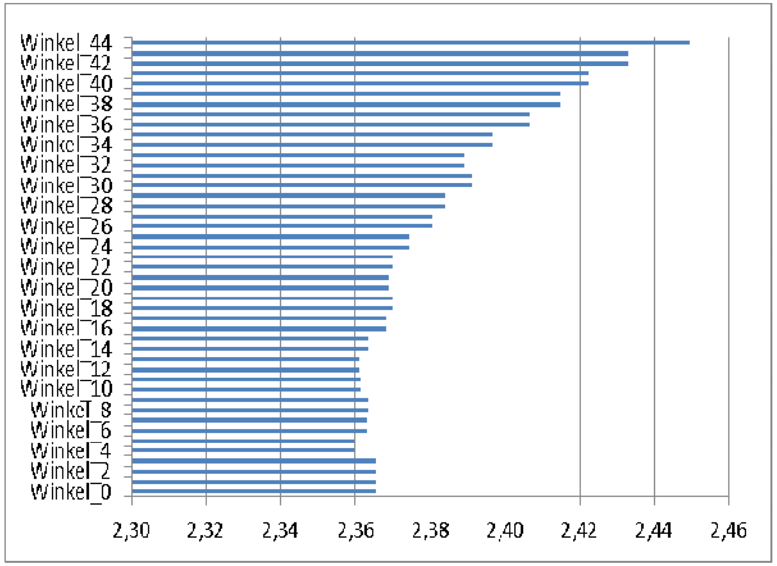


e.g. 20 x 20 litz strands

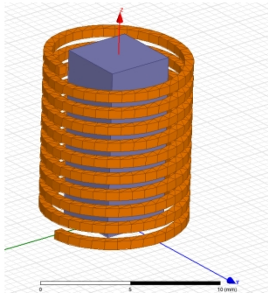
Results

- merge all 2D results and evaluate these according to criteria for convergence (differences between neighboring cuts should be smaller than a critical value according to their losses), if the difference is larger, additional adaptive cuts are performed
- transfer of the results to an Excel sheet
- presentation and visualization of the data

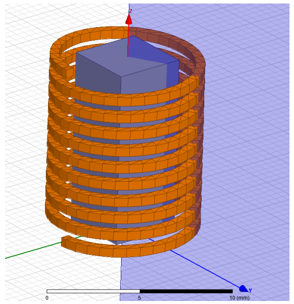




SLICER - overview

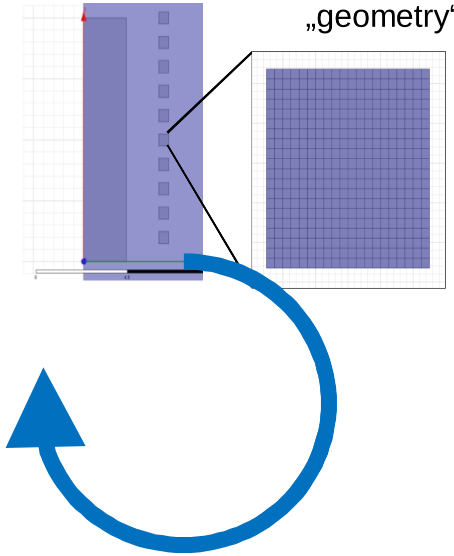


CAD input in Maxwell3D



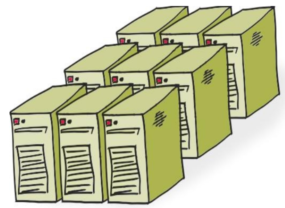
Setup and preparation of the 2D geometry

Implementation of substructures and copy of the 2D projects in a separate folder (e.g. „geometry“)



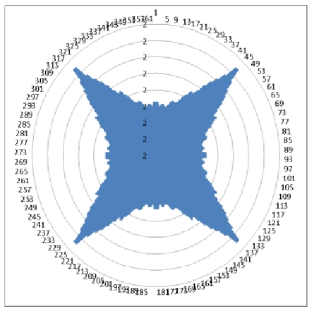
Control Script (~500 lines of code)
(via Visual Basic [Excel] or Python)
Definition of all parameters, material detection, convergence, substructure, initial conditions, parallelization, etc.

Separate script controls „geometry“-folder and sends each 2D project to the HPC cluster for computation



(very good parallelization, due to each project being independent)

Results:
Calculation of losses in the whole 3D geometry by interpolating the 2D results



Convergence
Stop, if the needed accuracy is reached

Results:
...
Winkel_42 – 2.42
Winkel_44 – 2.58
Winkel_46 – 2.48
...

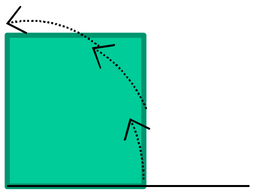
Real-time check of the results and induction of additional cuts if necessary

SLICER - accuracy

In the case of a completely rotational symmetric or linear 3D geometries, we achieve an accuracy in the order of the error of Maxwell3D.

By using the SLICER and having partially symmetric or even arbitrary geometries, the accuracy mainly depends on the geometry itself and the number of cuts. The geometry in one cut is assumed to be constant until the next cut – the results in all 2D cuts are summed up and weighted according to their ratio in the whole 3D geometry.

Example:



real geometry

approximation by 3 cuts (fixed angle of 30)

Initially the 2D cuts are realized with an fixed angle of 1 -3 , reaching a quite good approximation of the real geometry.

SLICER - Conclusions

- For the litz wire system we have demonstrated that we can achieve a good approximation of the losses on a 3D geometry by using the SLICER methodology
- Our method has been designed and implemented in a generic way, thus it is not limited to the usage with Maxwell3D
- Beyond the litz wire system shown, there are many other applications which can benefit from the methodology, e.g.
  - multiscale modeling of processes in (semiconductor) technology such as processing of micro-structured substrates in macroscopic equipment
  - integrated simulation of on-chip wiring and package components for instance with respect to parasitics extraction
  - optical properties of nano- or micro-structured surfaces for optical elements
- Extensions of the method are under development which allow
  - even more general geometries to be treated
  - calculation and control of the numerical error