

3d magnetostatic and eddy current calculations in the time domain

Validation of magnetostatic and eddy current calculations

<https://github.com/JNSresearcher/ECMS3D>

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1 Magnetostatic testing

During validation, the results of calculations in [Elmer FEM](#), [PyPEEC](#) and **ECMS3D** were compared. Fig.1 shows the sizes of the regions for the test example. The control lines is **V1** and **V2** .

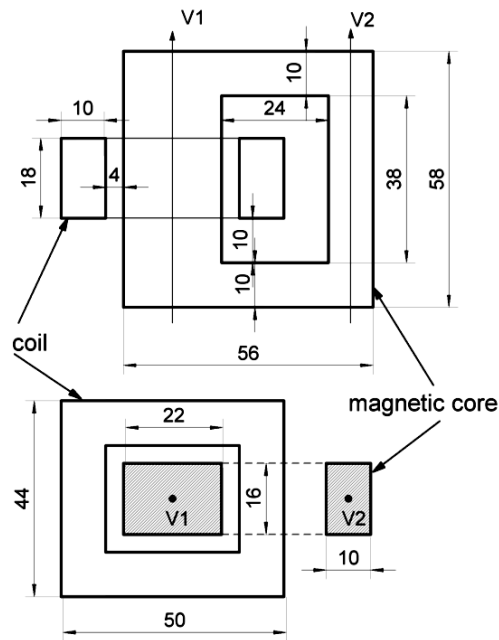
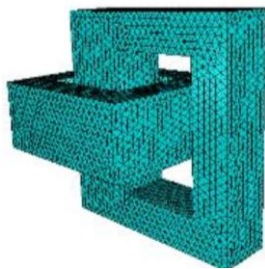
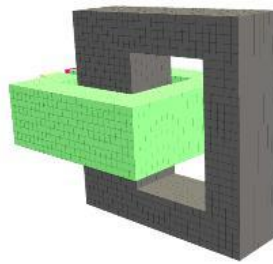


Fig.1. Region sizes for the test example.

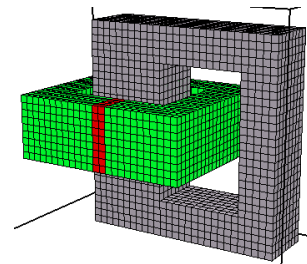
The coil current is **18 A**. The relative magnetic permeability of the magnetic core is $\mu = 10$.



a) **ElmerFEM**



b) **PyPEEC**

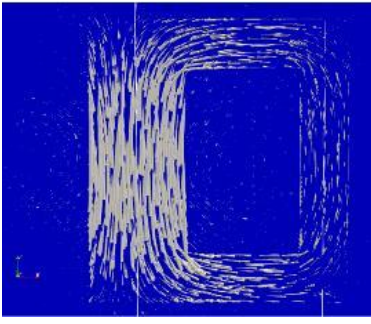


c) **ECMS3D** (prepared in

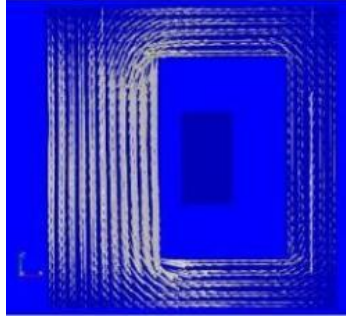
[VoxCAD](#))

Fig.2. Screenshots of geometry for calculations in **ElmerFEM**, **PyPEEC** and **ECMS3D**.

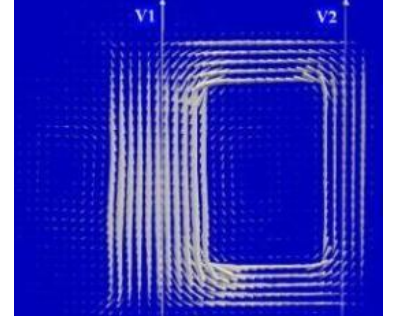
Below in Fig.3 the results of the calculation of the magnetic flux density, displayed in **Paraview**.



a) **ElmerFEM**



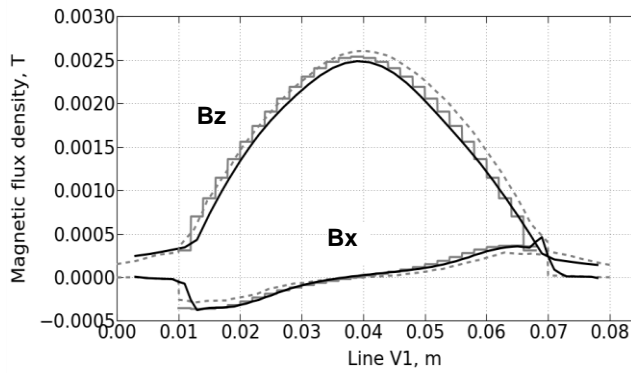
b) **PyPEEC**



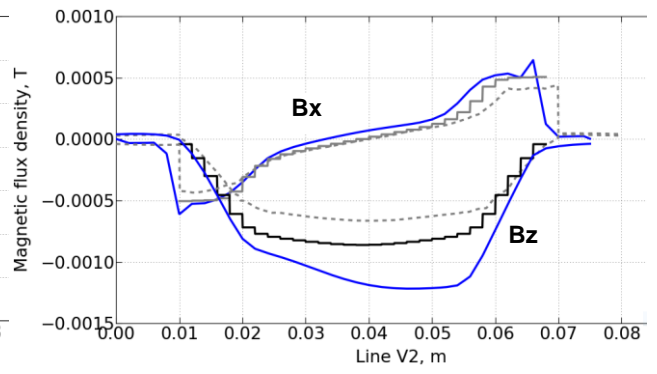
c) **ECMS3D**

Fig.3. Screenshots of magnetic flux density in the **XZ** plane along the middle part of the magnetic core.

Below in Fig.4 are graphs of the **x- z-** components of the magnetic flux density along the control lines. The positive directions along the control lines are shown in Fig.1



a) Magnetic flux density along line **V1**



b) magnetic flux density along line **V2**

Fig.4. Graphs of the magnetic flux density. Solid lines of the graphs correspond to calculations in the **ECMS3D** stepped line correspond to calculations in the **PyPEEC**, dotted lines correspond to calculations in the **ElmerFEM**.

It can be seen from Fig.4 that the **ECMS3D** calculations using the *Intel mkl pardiso* library simulation results agree well with the **Elmer FEM** and **PyPEEC**. The discrepancy is observed along line **V2** for **Bz**. Calculations using *GMRES* give almost identical results. Calculations using *BiCGSTABwr* to calculate magnetostatics do not work (perhaps due to the strong asymmetry of the formula $\nabla \times \nabla \times \vec{A}$).

2 Testing the interaction of eddy currents and magnetostatic.

During validation, the results of calculations in *Elmer FEM* and **ECMS3D** were compared.

Figure 5 shows the sizes of the regions for the test example. The line **H** along which the results are checked is shown.

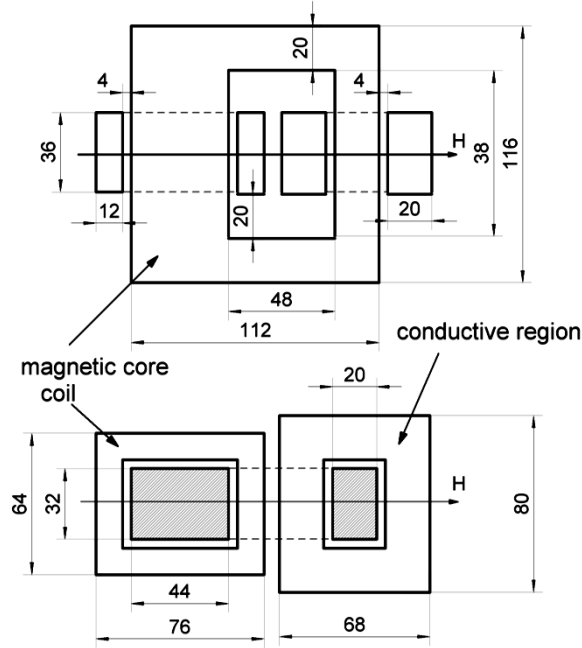
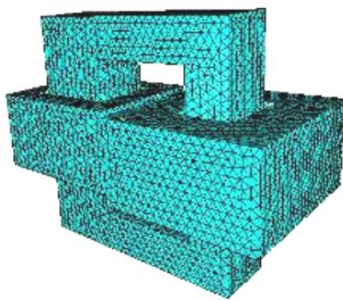


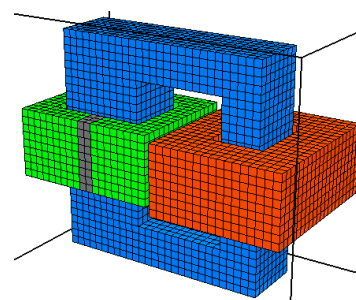
Fig.5. Region sizes for the test example.

A sinusoidal current with amplitude of **18 A** and a frequency of **50 Hz** is set in the coil. The electrical conductivity of the conductive region is $\sigma = 35.26 \cdot 10^{-6} \text{ S / m}$. The relative magnetic permeability of the magnetic core is $\mu = 10$.

Below in Fig.6 are screenshots taken in **ElmerFEM** and **VoxCAD** (geometry prepared for **ECMS3D**).

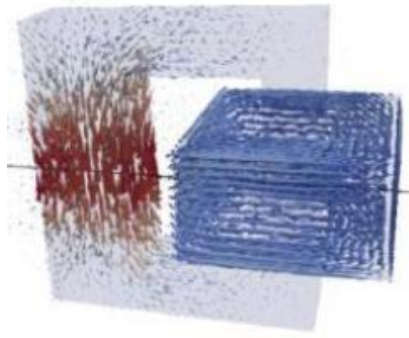


a) geometry for **ElmerFEM**

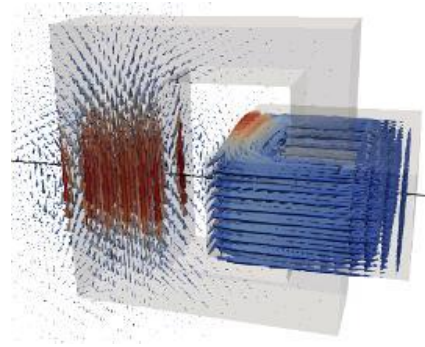


b) geometry for **ECMS3D**
(prepared in **VoxCAD**)

Fig.6. Screenshots of geometry for calculations in **ElmerFEM** and **ECMS3D**.



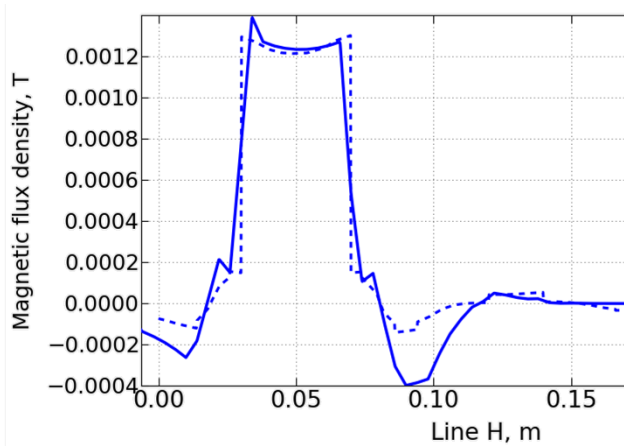
a) **ElmerFEM**



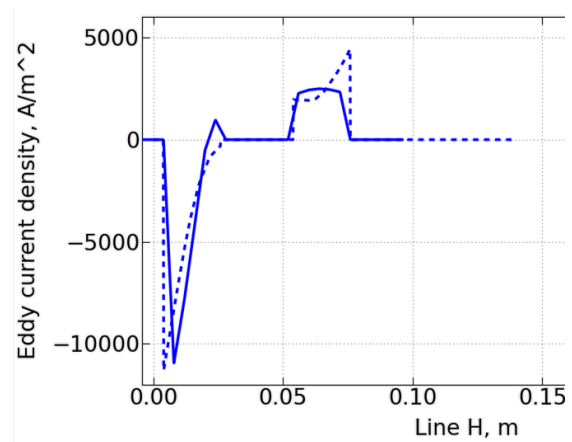
b) **ECMS3D**

Fig.7. Images of magnetic flux density and eddy current density distribution calculated in **ElmerFEM** and **ECMS3D** and displayed in **Paraview**.

Below in Fig.8 a comparison of the results of calculating the distribution of magnetic flux density and eddy current density along the test line **H** is shown.



a) **z**-component of magnetic flux density



b) **y**-component of eddy current density

Fig.8. Graphs of the magnetic flux density and the eddy current density.
Solid lines of the graphs correspond to calculations in the **ECMS3D**,
dotted lines correspond to calculations in the **ElmerFEM** at time
 $t=0.017\text{sec}$.

As can be seen from Fig. 8, the results of modeling in **ECMS3D** (the *Intel MKL pardiso* library was used) generally correspond to the results of **ElmerFEM**.

Calculating 100 points from 0 to 100ms in **ElmerFEM** took **869s**, in **ECMS3D** using *Intel MKL pardiso* it took **85s**, and using *GMRES* it took **98s** (*Intel MKL pardiso* and *GMRES* have practically the same results).

3 Testing of calculations of a single-sided linear induction machine (LIM).

For verification calculations of eddy currents in **LIM**, the [Agros2d](#) program was chosen.

In this program, you can specify the motion of a conducting domain with a constant velocity in Euler coordinates. Although **Agros2d** is designed to solve *2D* problems, it can be used for testing if its solution is compared with the solution obtained in the middle part of a *3D* problem (the cutting plane must be located along the coordinate in the direction of movement and along the second coordinate in the perpendicular direction).

The relative velocity of the three-phase winding and the conducting domain can be defined as a domain property in Euler coordinates. In the three-dimensional analogue of this problem, the cutting plane is located along the coordinate in the direction of motion and along the second coordinate in the perpendicular direction.

Fig.9 shows the sizes of the regions for the test example. The line **H** along which the results are checked is shown.

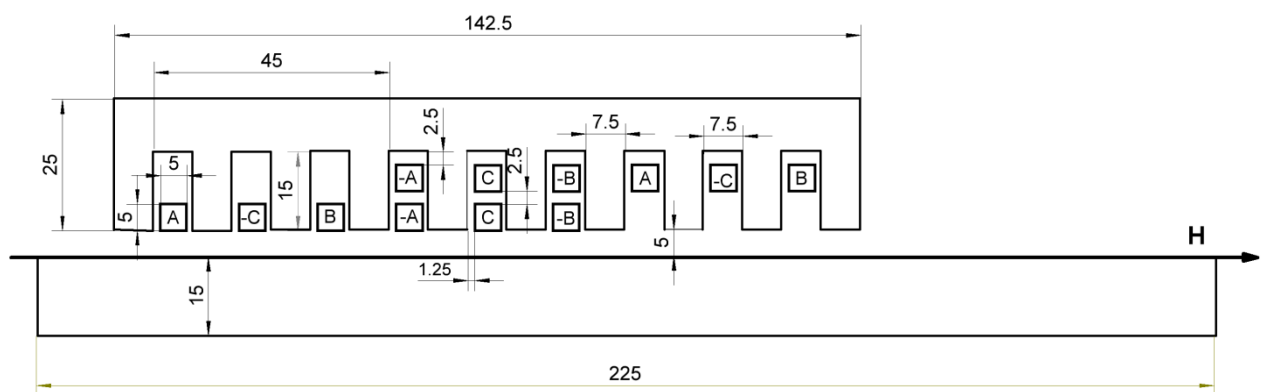


Fig.9. Region sizes for the test example.

A sinusoidal current with an amplitude of **10 A** and a frequency of **28.6 Hz** is supplied to the three-phase coils. The electrical conductivity of the conductive region is $\sigma = 35.26 \cdot 10^6 \text{ S / m}$. The relative magnetic permeability of the magnetic core is $\mu = 100$.

Below in Fig.10 are screenshots taken in **Agros2d** and **VoxCAD** (geometry prepared for **ECMS3D**).

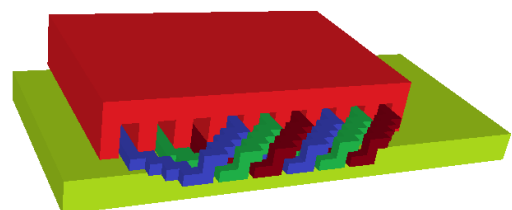
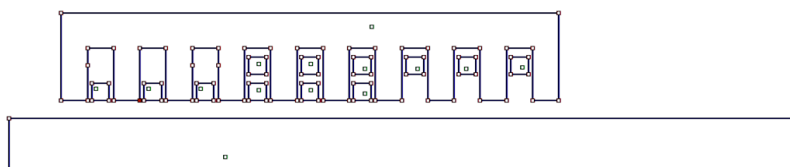


Fig.10. Screenshots of geometry for calculations in **Agros2d** and **ECMS3D**.

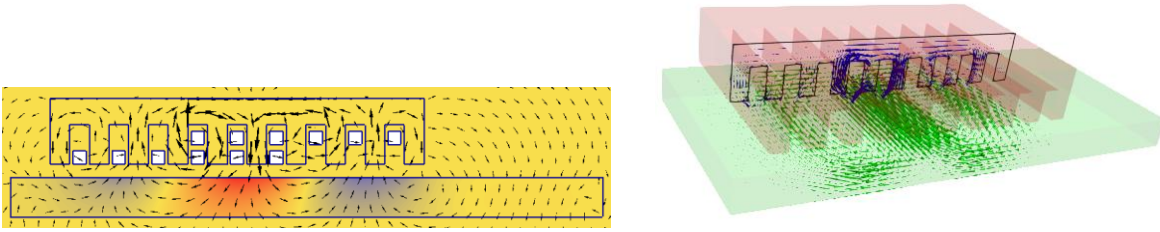
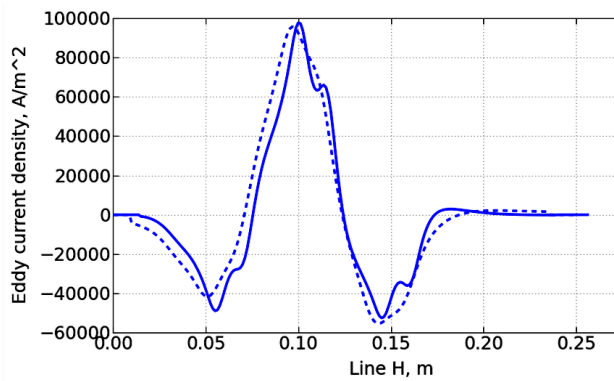
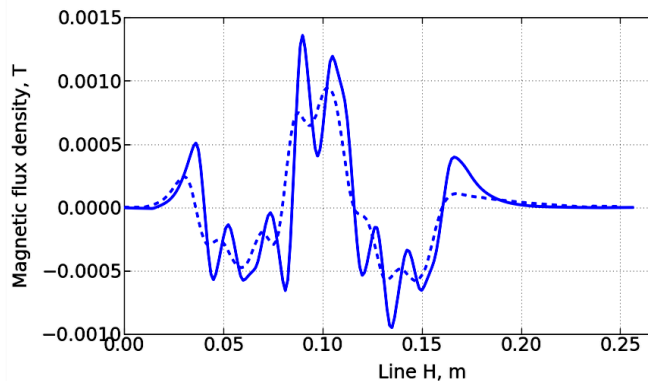


Fig.11. Screenshots of magnetic flux density and eddy current density distribution calculated in **Agros2d** (on the left) and **ECMS3D**. (on the right). In a 3-d problem the section is located in a plane **XZ**.

Below in Fig.12 a comparison of the results of calculating the distribution of magnetic flux density and eddy current density along the test line **H** at zero velocity of the conducting region is shown.



b). eddy current density
(**y**- component for a 3-d problem)



a). magnetic flux density
(**z**-component for a 3-d problem)

Fig.12. Graphs of the eddy current density and the magnetic flux density.
Solid lines of the graphs correspond to calculations in the **ECMS3D**, dotted lines correspond to calculations in the **Agros2d** at time **$t=0.017\text{sec}$**

Below in Fig.13 a comparison of the results of calculating the distribution of magnetic flux density and eddy current density along the test line **H** is shown if the conductive region moves in the positive direction of the **X**-axis at a speed of **$V_x=2.5\text{ m/s}$** .

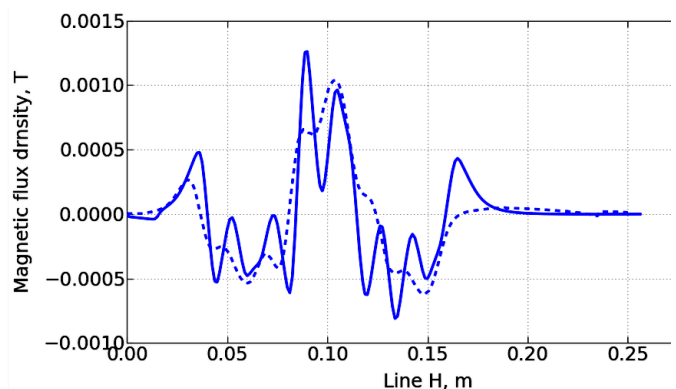
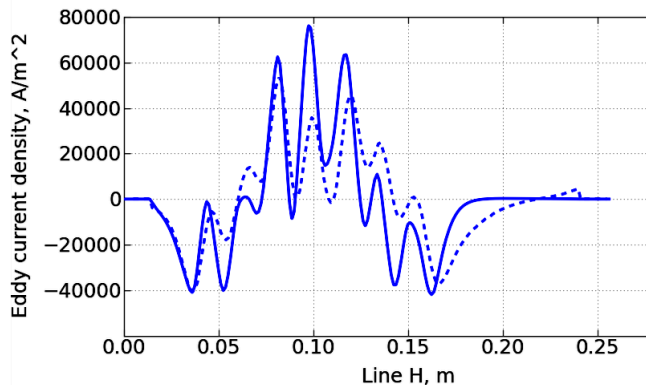


Fig.13. Graphs of the eddy current density and the magnetic flux density.
Solid lines of the graphs correspond to calculations in the **ECMS3D**, dotted lines correspond to calculations in the **ElmerFEM** at time **$t=0.017\text{sec}$**