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ArcelorMittal

Calculating Iron Losses taking into account manufacturing processes

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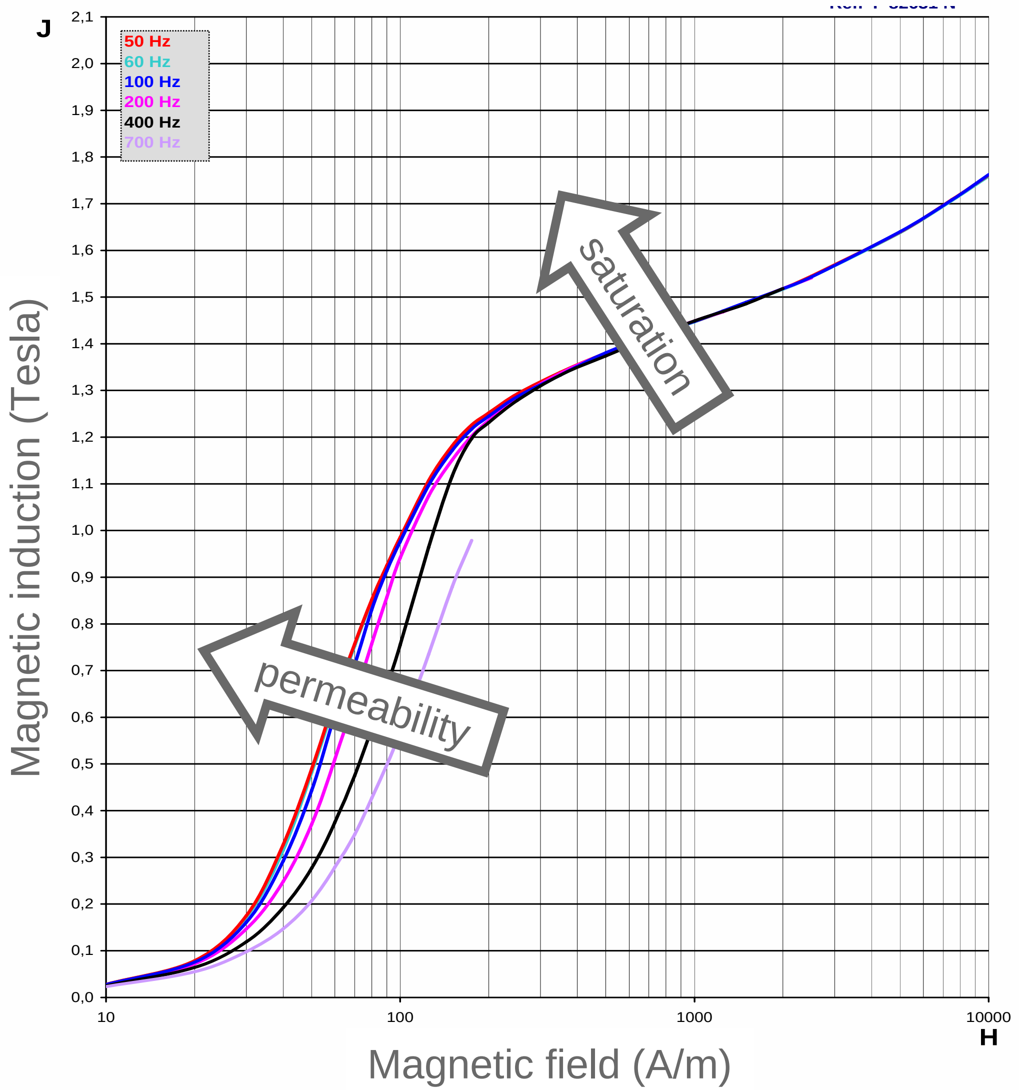
ArcelorMittal Research Gent - Belgium

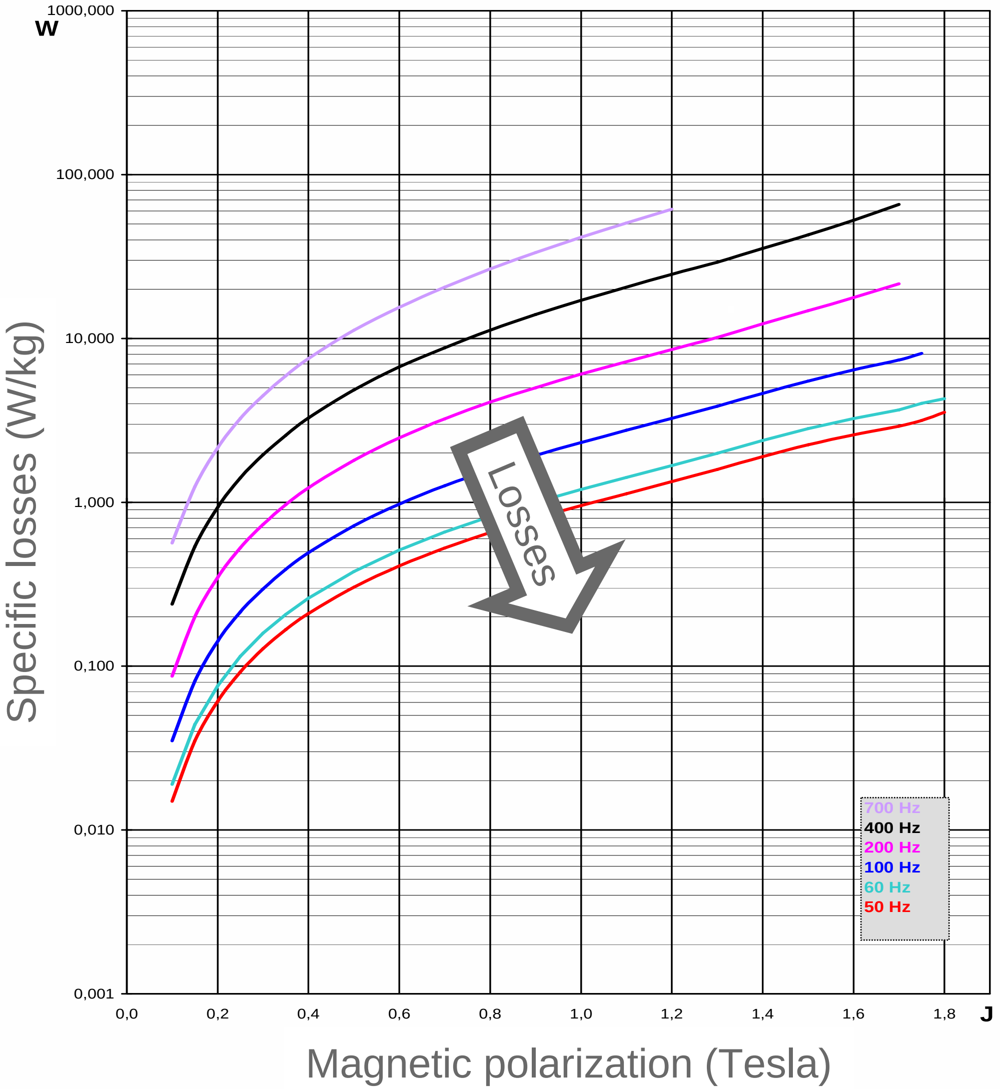
- Development of high quality electrical steels
  - High permeability
  - High saturation
  - Low loss
- Assisting customers in applying them
  - FE modelling

Improving magnetic properties



- Increase saturation
  - Reduce Si and Al
- Increase permeability
  - Improve texture

Improving losses

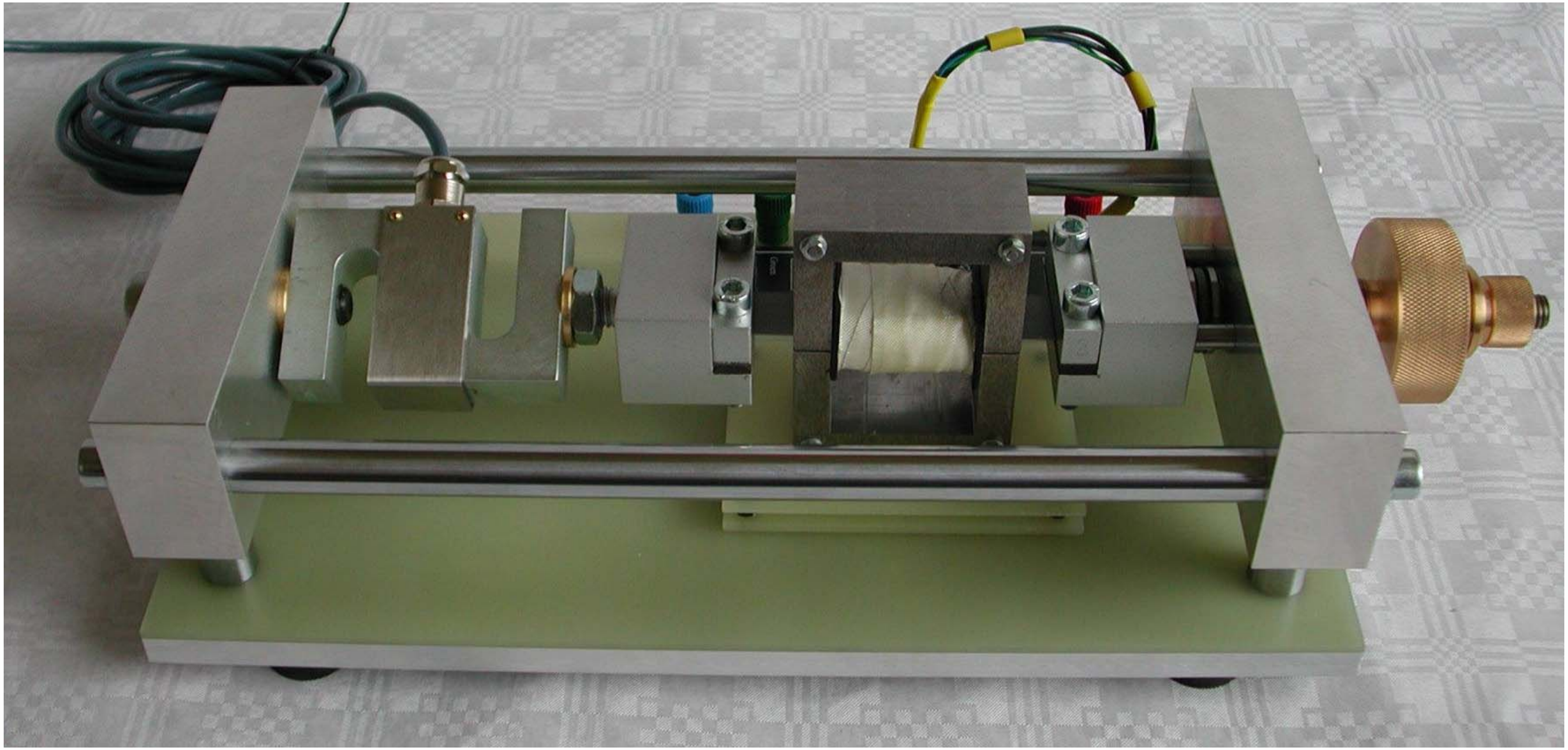


- Reduce eddy current loss
  - Reduce conductivity
    - Increase Si and Al
  - Reduce lamination thickness
  - Improve coatings
- Reduce hysteresis loss
  - Improve microstructure

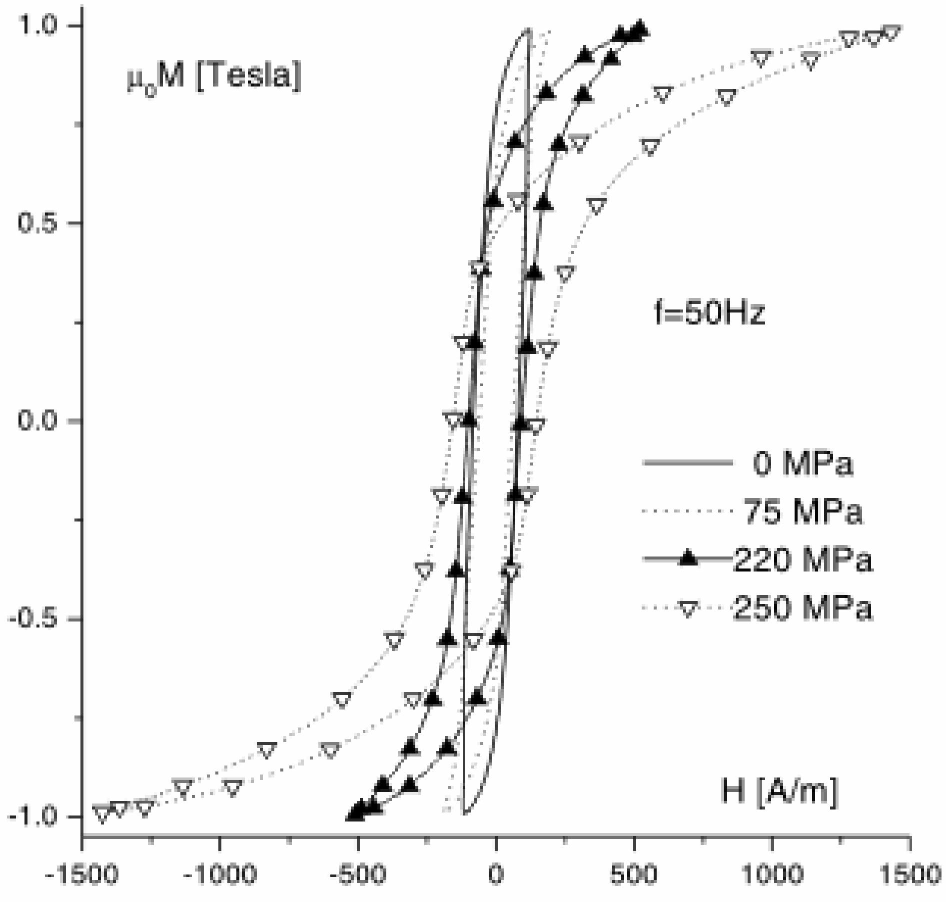
Excellent steel can be ruined

- By mistreating it
- E.g.
  - Laser cutting with high heat input
  - Stressing during assembly
    - E.g. shrink fitting the housing onto the stator
- Quantify
  - Measure the effects of mechanical stress
  - Determine mechanical stress through modelling

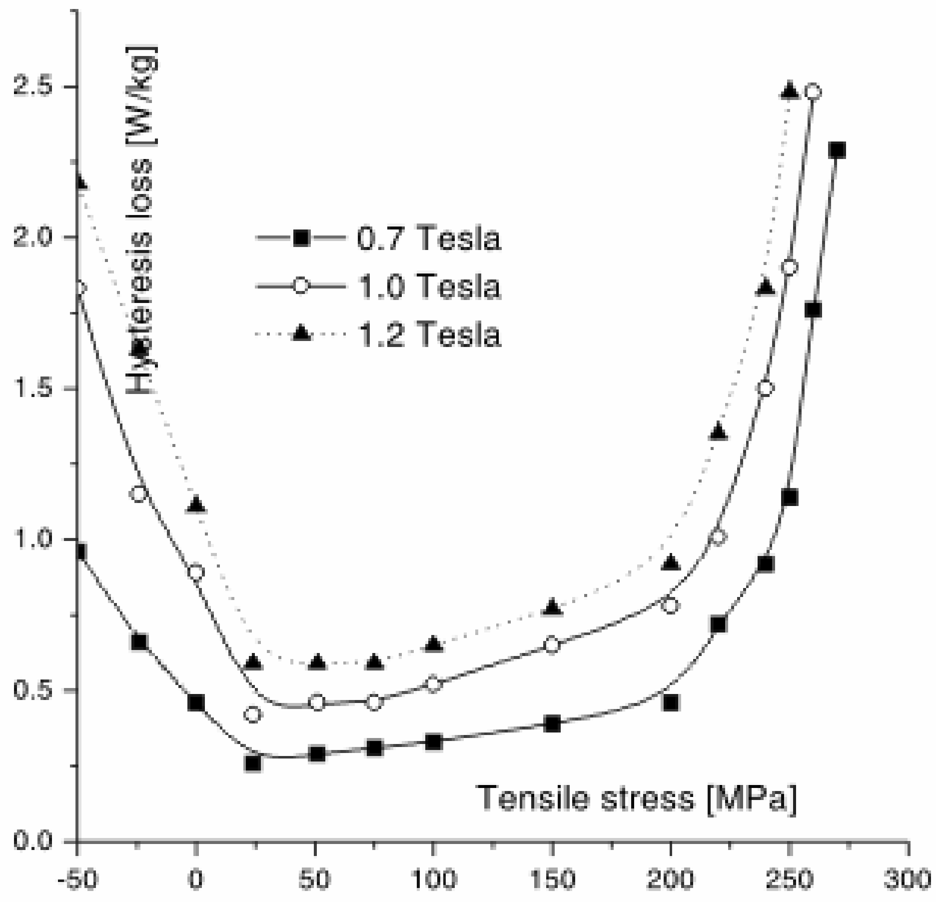
Measuring magnetic properties under uniaxial stress



Hysteresis loops: function of mechanical stress

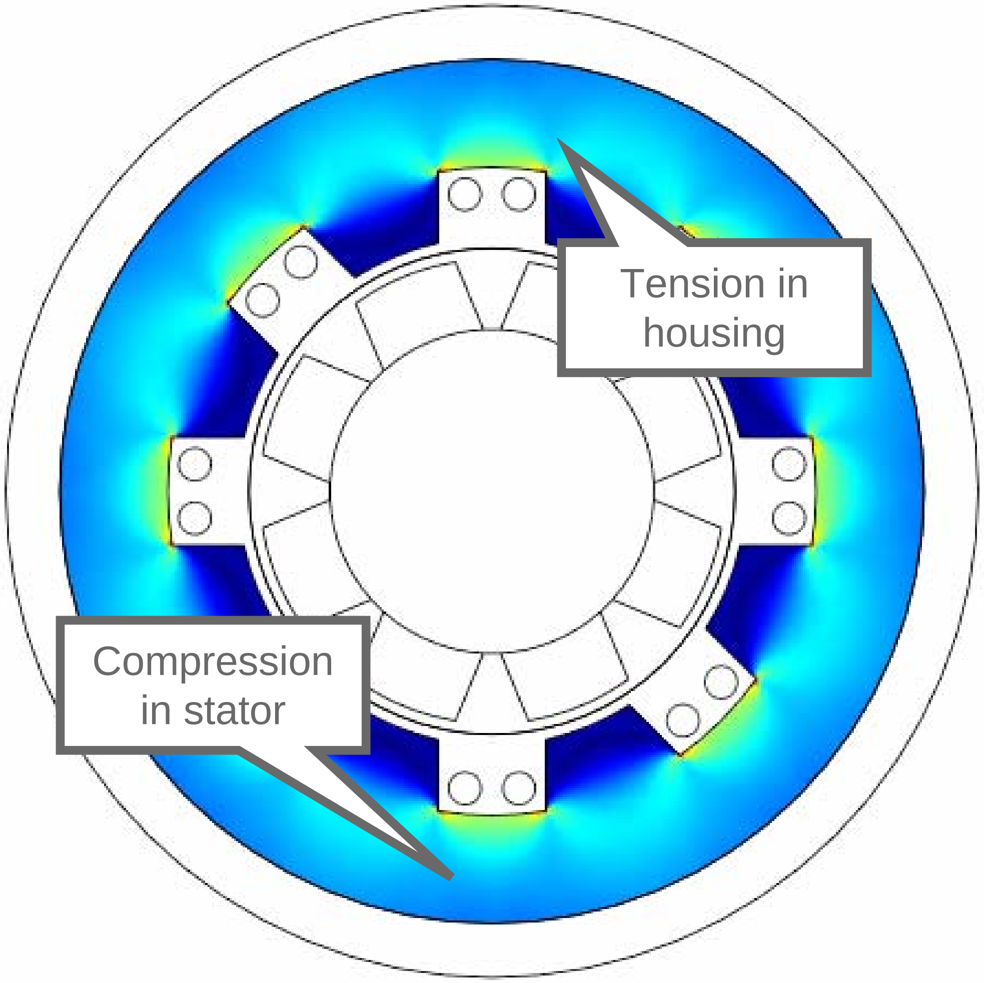


Hysteresis losses : function of mechanical stress

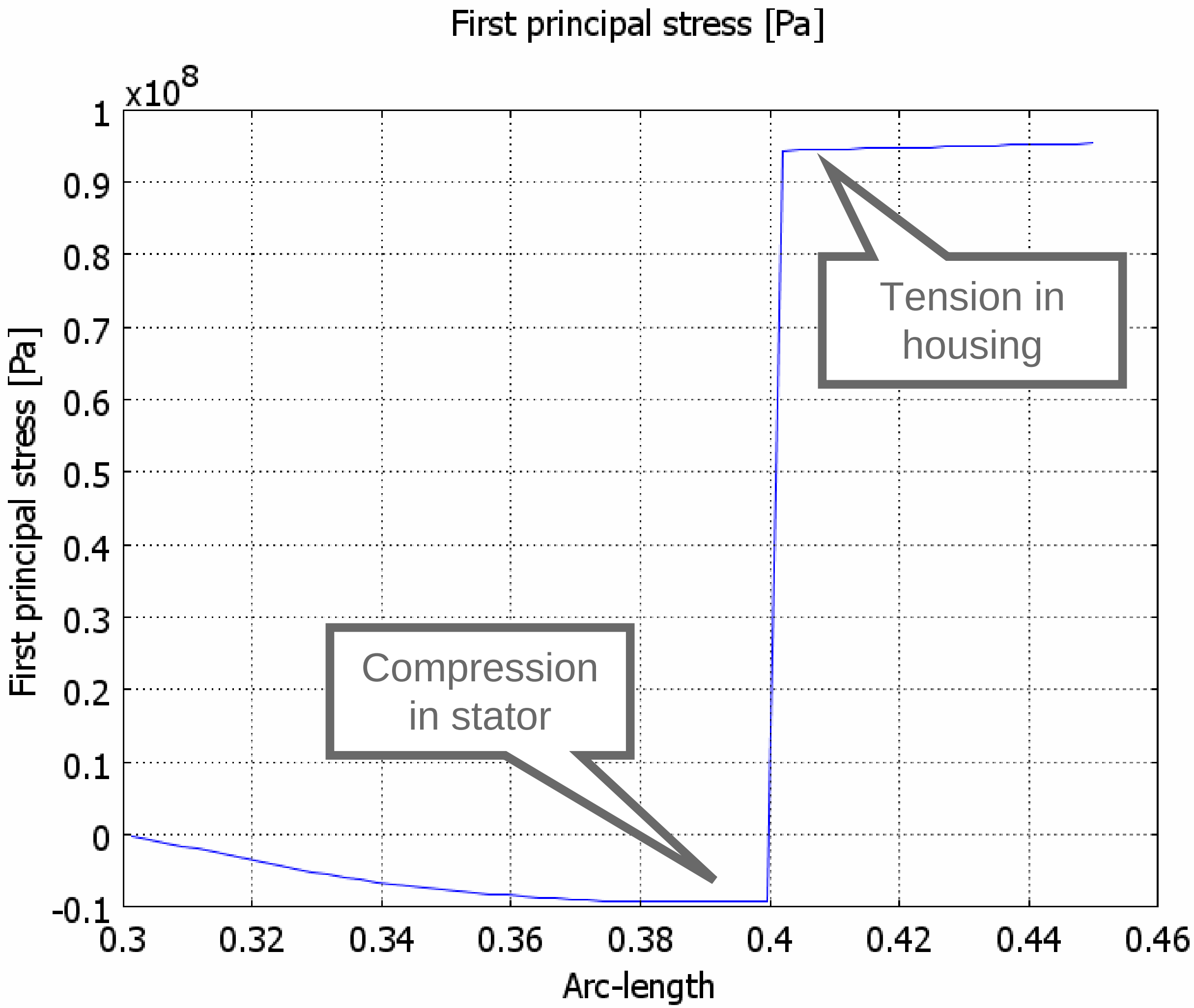


Modelling it

- Calculate stresses using the structural mechanics module's "plane strain" application mode (smpn)
- Modify the AC/DC module's "perpendicular currents" application mode (emqa) to extend the material's constitutive relations to include the stress dependence



- Define motor geometry
- Add housing
- Include thermal expansion
- Solve for Plane Strain
- Get the Mises stress
- Stator only
- Line plot



- Define motor geometry
- Add housing
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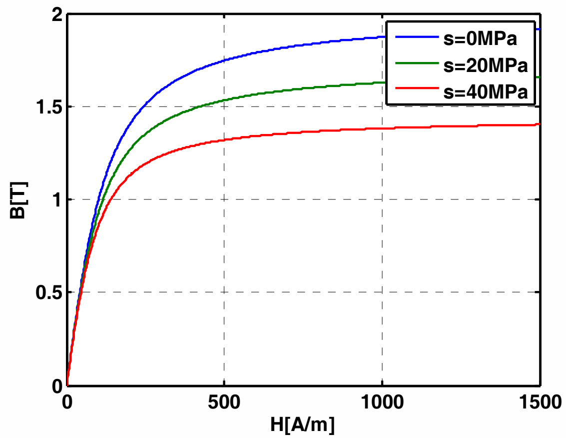
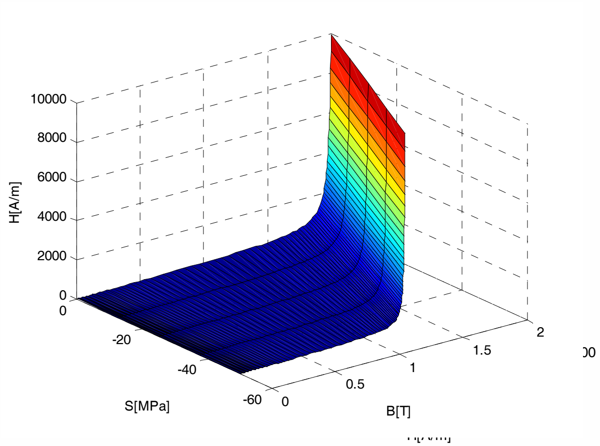
Extend AC/DC emqa application mode

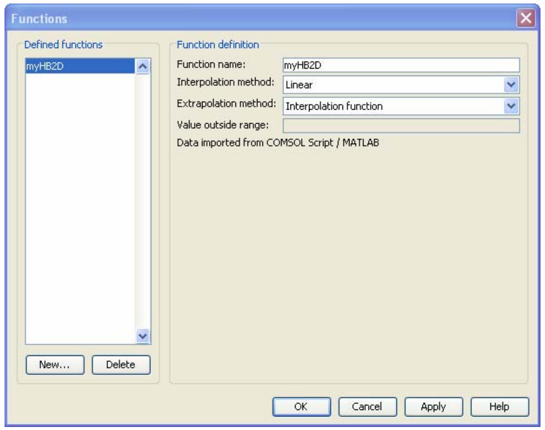
- Emqa:
  - Perpendicular induction currents
  - Vector potential, component Az only
- Constitutive relation:
  - Emqa contains: $H = f(|B|).e_B$
  - We need: $H = f(|B|,S).e_B$

Adding the H(B,S) function





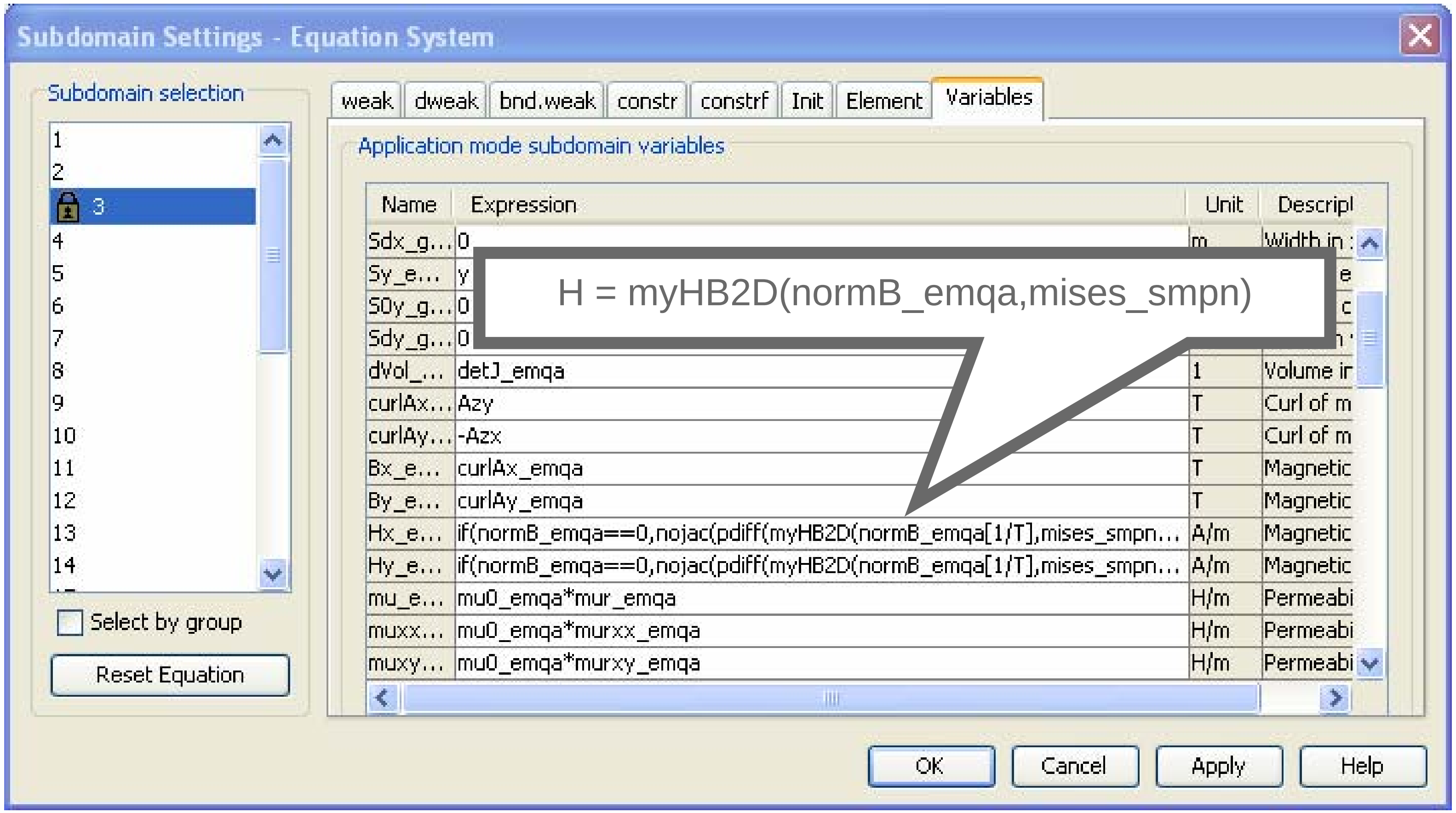
- B(H) for different S values
- B(H,S) function
- Emqa needs H(B,S), not B(H,S)
- So invert the function
- Define it as an interpolation function



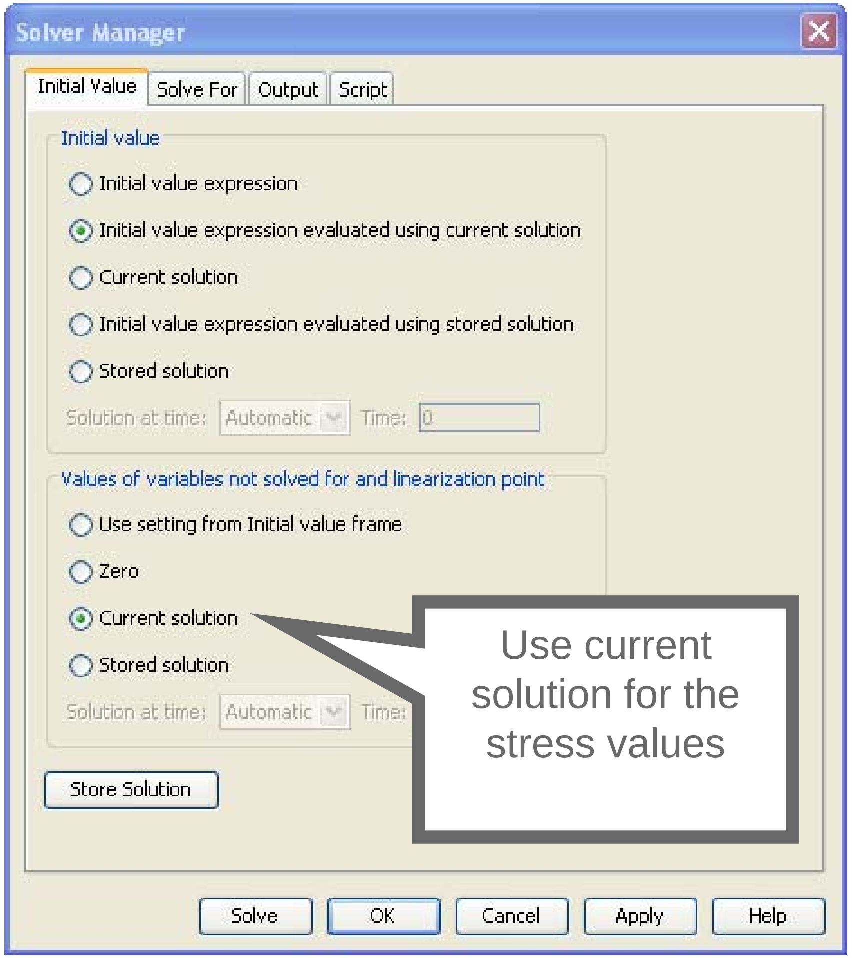
HB-function in the m-file

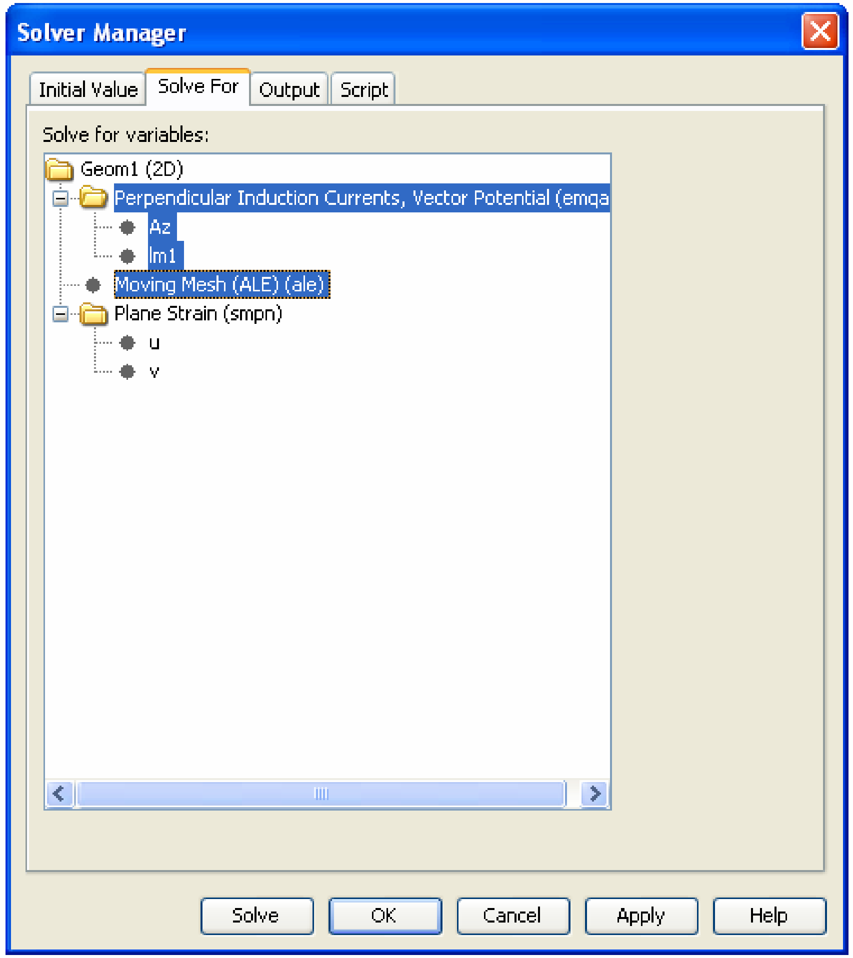
```
% Functions
clear fcns
fcns{1}.type='interp';
fcns{1}.name='myHB2D';
fcns{1}.method='linear';
fcns{1}.extmethod='extrap';
fcns{1}.x={'0.1','0.119047167667739','0.138094335335478', ...
  '0.157141503003218','0.176188670670957','0.195235838338696', ...
  '0.214283006006435','0.233330173674175','0.252377341341914', ...
  '0.271424509009653','0.290471676677392','0.309518844345131', ...
  '0.328566012012871','0.34761317968061','0.366660347348349', ...
  '0.385707515016088','0.404754682683828','0.423801850351567', ...
  '0.442849018019306','0.461896185687045','0.480943353354784', ...
  '0.499990521022524','0.519037688690263','0.538084856358002', ...
  '0.557132024025741','0.57617919169348','0.59522635936122', ...
```

Edit the equation system



And solve…

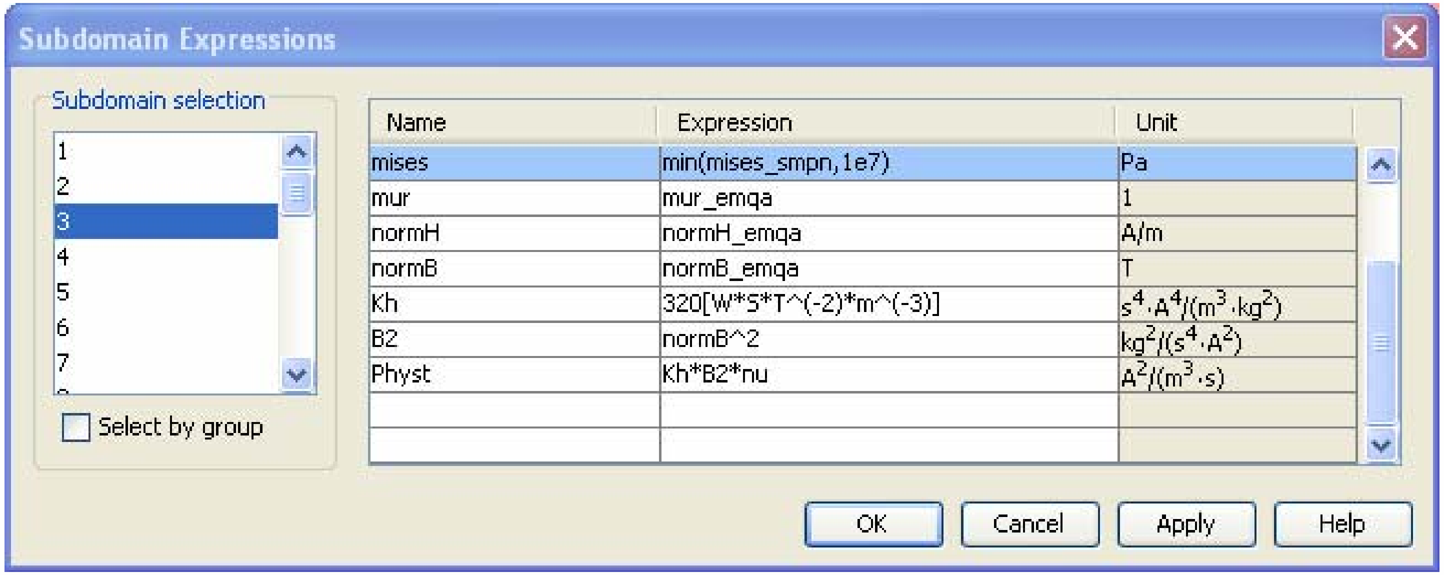

Solver Manager
Initial Value
Solve For
Output
Script
Initial value
Initial value expression
Initial value expression evaluated using current solution
Current solution
Initial value expression evaluated using stored solution
Stored solution
Solution at time:
Automatic
Time:
0
Values of variables not solved for and linearization point
Use setting from Initial value frame
Zero
Current solution
Stored solution
Solution at time:
Automatic
Time:
Store Solution
Use current solution for the stress values
Solve
OK
Cancel
Apply
Help


Solver Manager
Initial Value
Solve For
Output
Script
Solve for variables:
Geom1 (2D)
Perpendicular Induction Currents, Vector Potential (emqa
Az
Im1
Moving Mesh (ALE) (ale)
Plane Strain (smpn)
u
v
Solve
OK
Cancel
Apply
Help

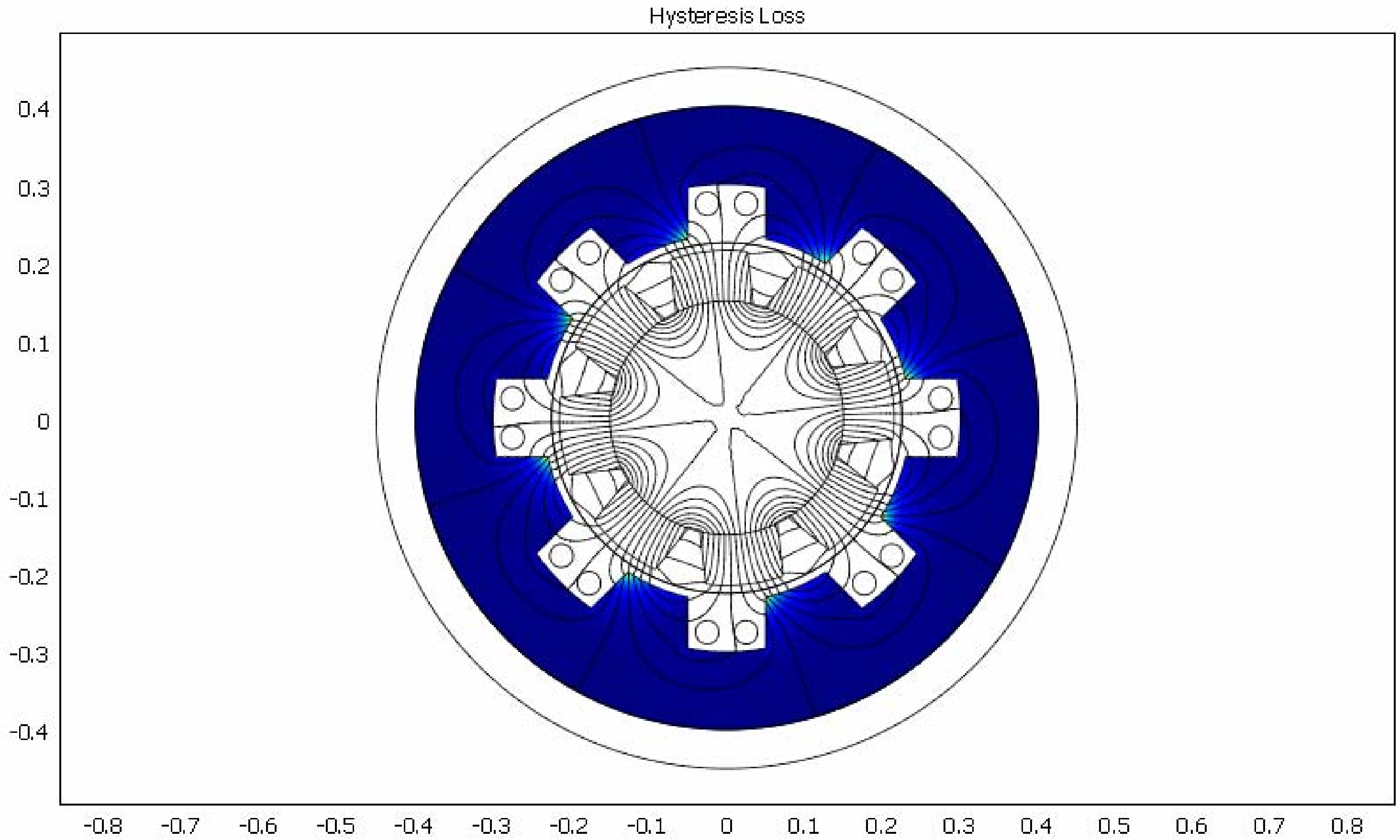
Scripted…

```
% solve first the smpn to determine the stresses
% Solve problem
fem.sol=femstatic(fem, ...
              'solcomp',{'v','u'}, ...
              'outcomp',{'v','u'}, ...
              'ntol',1e-006);

% Save current fem structure for restart purposes
fem0=fem;

% solve then the emqa to determine the magnetic induction
% Solve problem
fem.sol=femstatic(fem, ...
              'u',fem0.sol, ...
              'solcomp',{'lm1','Az'}, ...
              'outcomp',{'v','u','lm1','Az'}, ...
              'ntol',1e-006);
```

Postprocessing



Postprocessing



Conclusion

- It proved reasonably straightforward to use the structural mechanics and AC/DC module to calculate iron losses
- Previous attempts at modelling this using Abaqus (for structural mechanics) and FLUX2D (for electromagnetics) were very elaborate and time-consuming
- We intend to perform similar simulations modelling other factors influencing the magnetic properties and losses, e.g. cutting edge effects

Thank you !

Any questions ?