Operation of an Electromagnetic Trigger with a Short-circuit Ring

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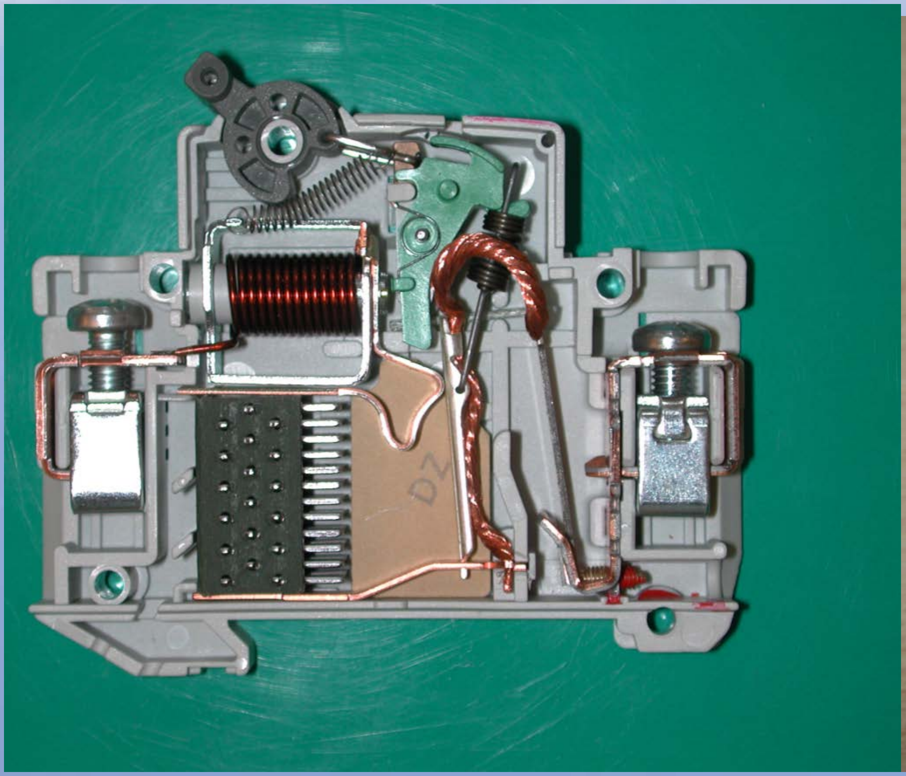
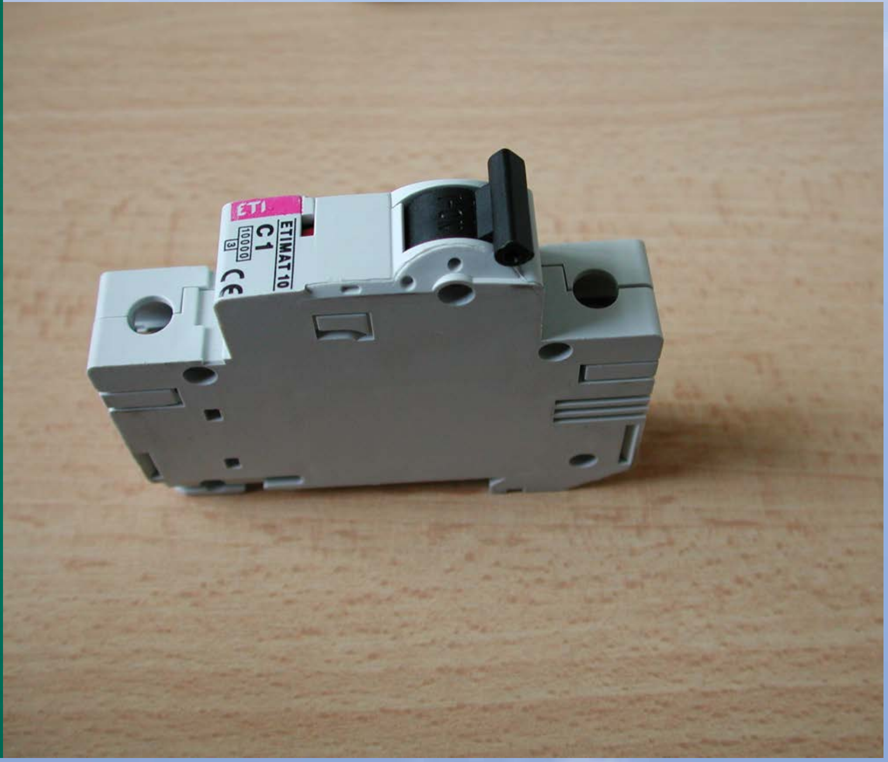
Outline

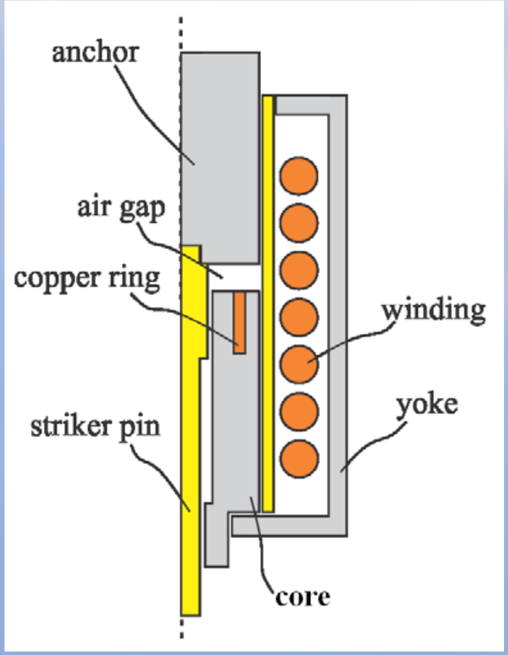
- Electromagnetic trigger
  - Usage
  - Selective circuit breaker
  - Problem of a movable contact
- Model
- Results
- Conclusions

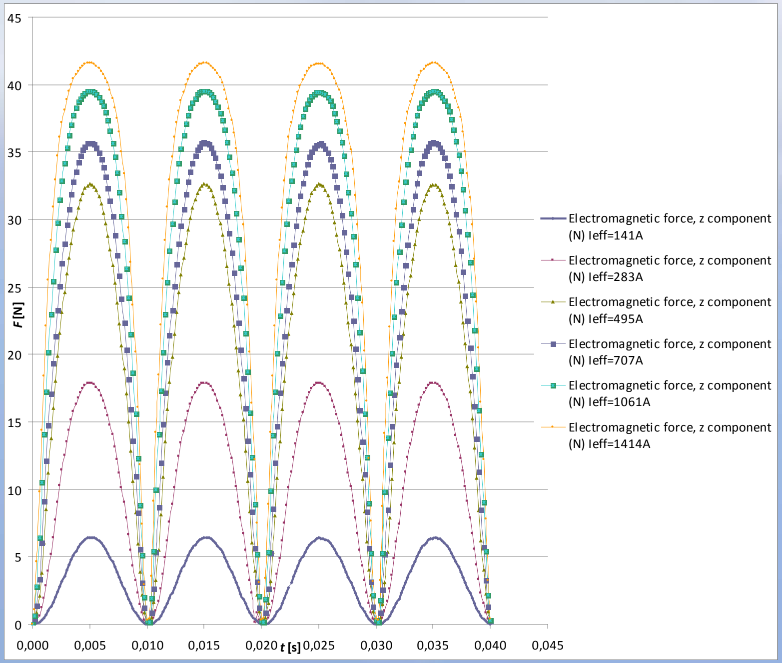
Miniature circuit breaker - MCB





Electromagnetic trigger



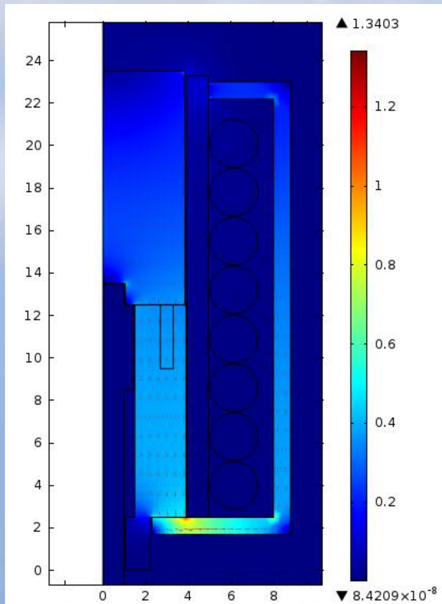


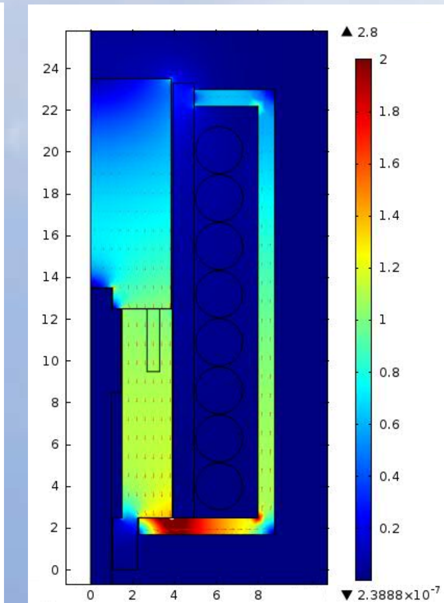
$$\sigma \frac{\partial \boldsymbol{A}}{\partial t} + \nabla \times \boldsymbol{H} = \boldsymbol{J}_{\mathrm{e}}$$

$$\boldsymbol{E} = -\nabla V - \frac{\partial \boldsymbol{A}}{\partial t}$$

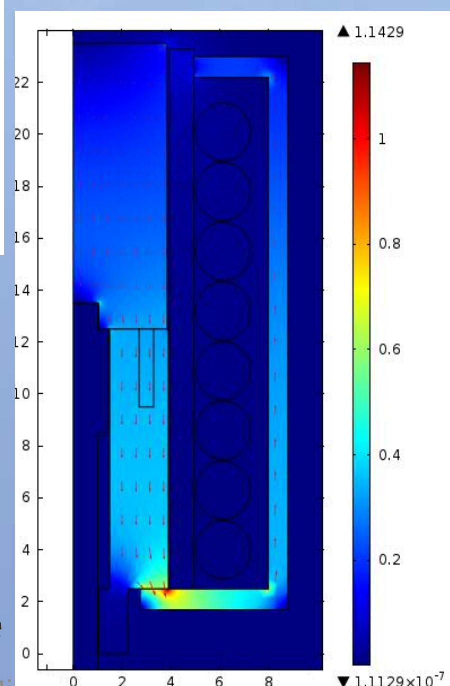
Results – without a ring

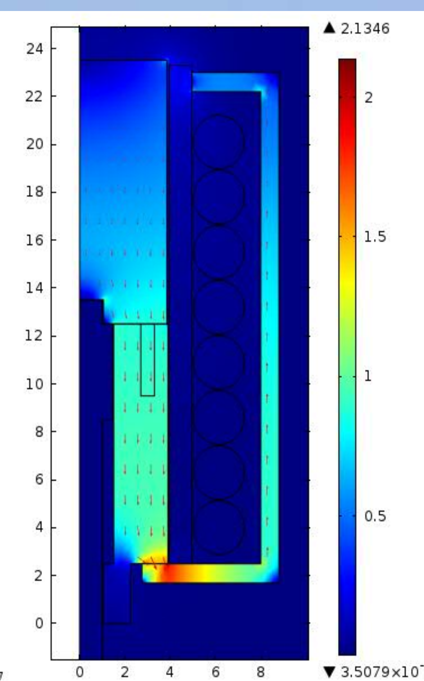
Absolute value of magnetic flux density at the current of a) 72A and b) 200 A.





Linearized B(H) curve

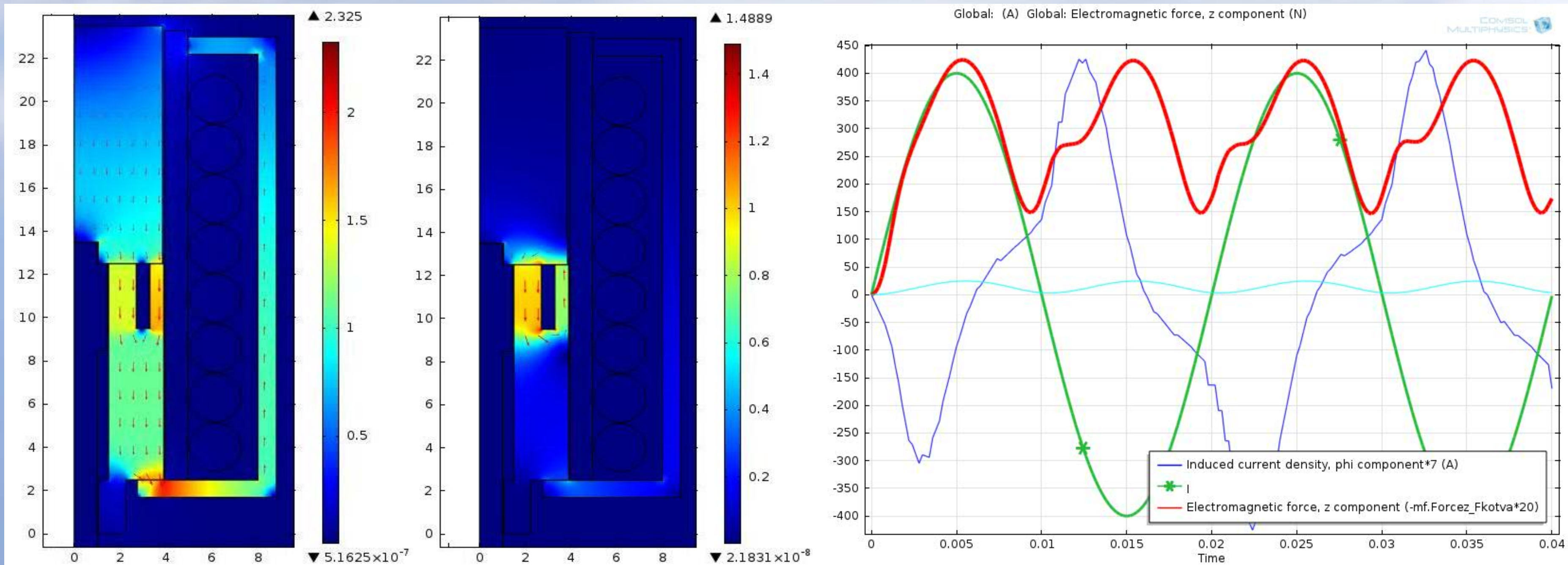


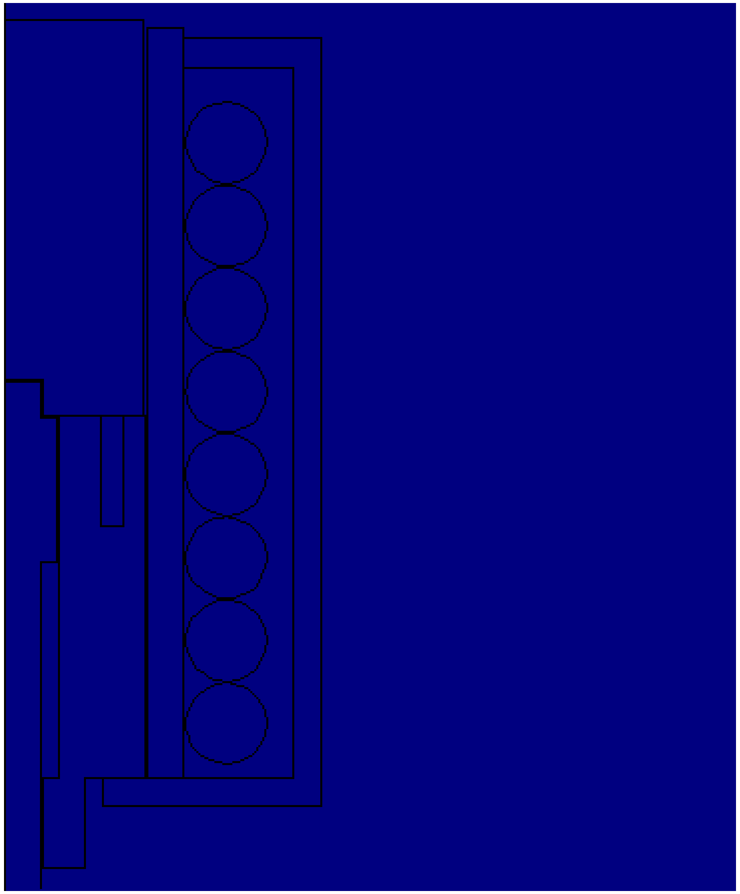


Tabulated B(H) curve

Results – ring included

Absolute value of magnetic flux density I_{RMS}=283A after a) 35 ms and after b) 40 ms.





Force calculation

$$\mathbf{F} = \oint_{\partial\Omega_1} \mathbf{n}_1 T_2 dS$$

$$\mathbf{n}_1 T_2 = -p\mathbf{n}_1 - \left(\frac{1}{2}\mathbf{E}\cdot\mathbf{D} + \frac{1}{2}\mathbf{H}\cdot\mathbf{B}\right)\mathbf{n}_1 + (\mathbf{n}_1\cdot\mathbf{E})\mathbf{D}^T + (\mathbf{n}_1\cdot\mathbf{H})\mathbf{B}^T$$

$$\mathbf{n}_1 T_2 = -\frac{1}{2}\mathbf{n}_1(\mathbf{H}\cdot\mathbf{B}) + (\mathbf{n}_1\cdot\mathbf{H})\mathbf{B}^T$$

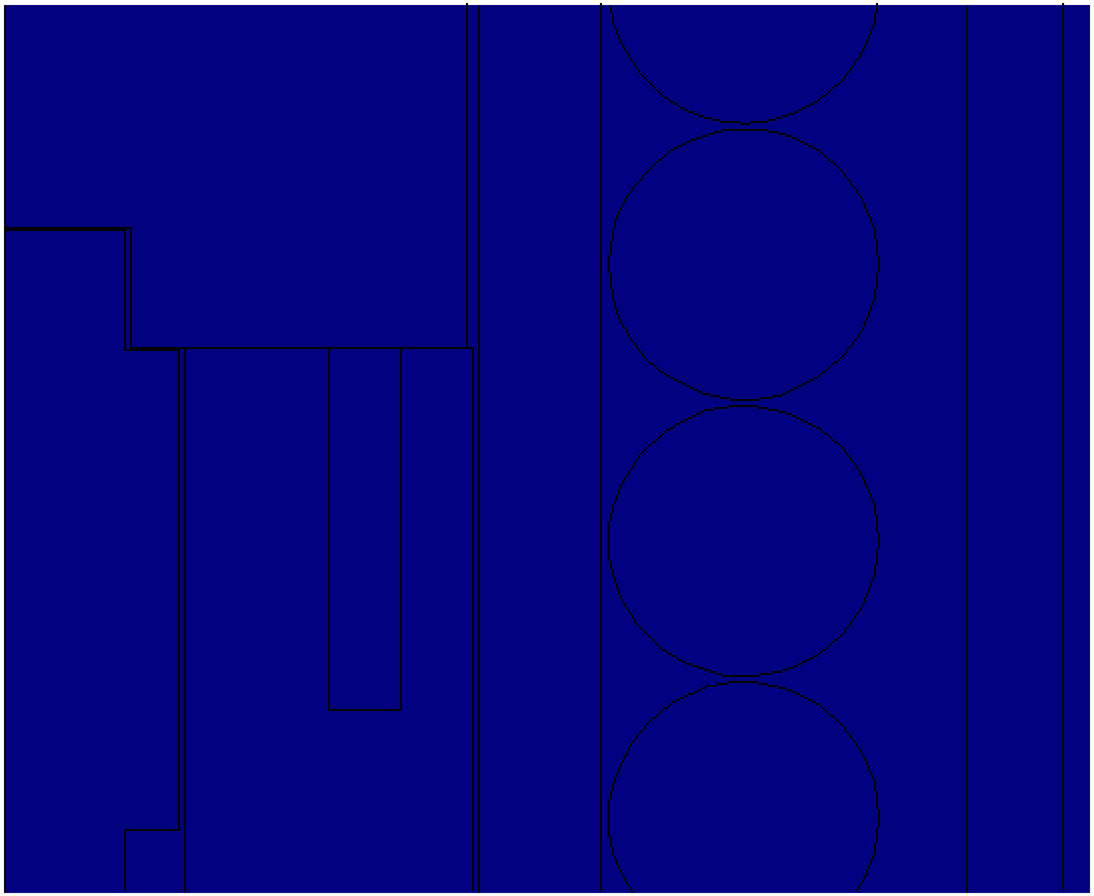
$$\boldsymbol{\tau} = \frac{1}{\mu_0}\begin{bmatrix} B_x^2 - \frac{1}{2}\boldsymbol{B}^2 & B_xB_y & B_xB_z \\ B_yB_x & B_y^2 - \frac{1}{2}\boldsymbol{B}^2 & B_yB_z \\ B_zB_x & B_zB_y & B_z^2 - \frac{1}{2}\boldsymbol{B}^2 \end{bmatrix}$$

$$\boldsymbol{F} = \oint_{\Gamma_j}\left(\frac{1}{\mu_0}B_n\boldsymbol{B} - \frac{1}{2\mu_0}\boldsymbol{B}^2\boldsymbol{n}\right)\mathrm{d}\Gamma = \oint_{\Gamma_j}\left(\frac{1}{2\mu_0}(B_n^2 - B_t^2)\boldsymbol{n} + \frac{1}{\mu_0}B_nB_t\boldsymbol{t}\right)\mathrm{d}\Gamma$$

$$f_t = \frac{1}{\mu_0}B_rB_t$$

$$f_r = \frac{1}{2\mu_0}\left(B_r^2 - B_t^2\right)$$

$$f = \frac{B_n^2}{2\mu_0} \approx \frac{\Phi^2}{2\mu_0 A^2}$$



Comsol adjustments

- Mesh: Typical number of mesh points was 28150.
- Study: A *Time Dependent simulation* (study) and *Magnetic Fields(mf)* physics
  - two *Ampere´s Law* sections (one for linear materials and one for nonlinear parts (anchor, yoke and core))
  - *Gauge Fixing for A-Field* was selected
- *Solver: Absolute tolerance* in the *Time Dependent Solver 1* settings for the first variable was set to Unscaled /1e-5 and for the second to Unscaled/8e-3. *Maximum BDF order* in *Time stepping method* solver was set to 2. Direct solver (in our case MUMPS) was used. In the *Fully Coupled 1* settings in the *Time Dependent Solver 1* section for Linear solver was selected *Direct* option, for Jacobian update was selected *On every iteration* option and *Maximum number of iteration* was set to 25.

Conclusions

- ✓ Operation of an electromagnetic trigger with a short circuit ring has been successfully studied by numerical simulation.
- ✓ Operation of the device at high currents resulting in magnetic field saturation effects requires some tuning of Solver parameters.
- ✓ Nonzero anchor force at zero current in coils is a result of induced current in the ring adding a tangential component to the force.
- ✓ Comsol Multiphysics is becoming on of the key players in the ever more important field of multiphysics modeling.

Results – just a video

Tule video z ringom