Moscow Power Energetic Institute

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Simulation of the Low-Voltage DC Arc

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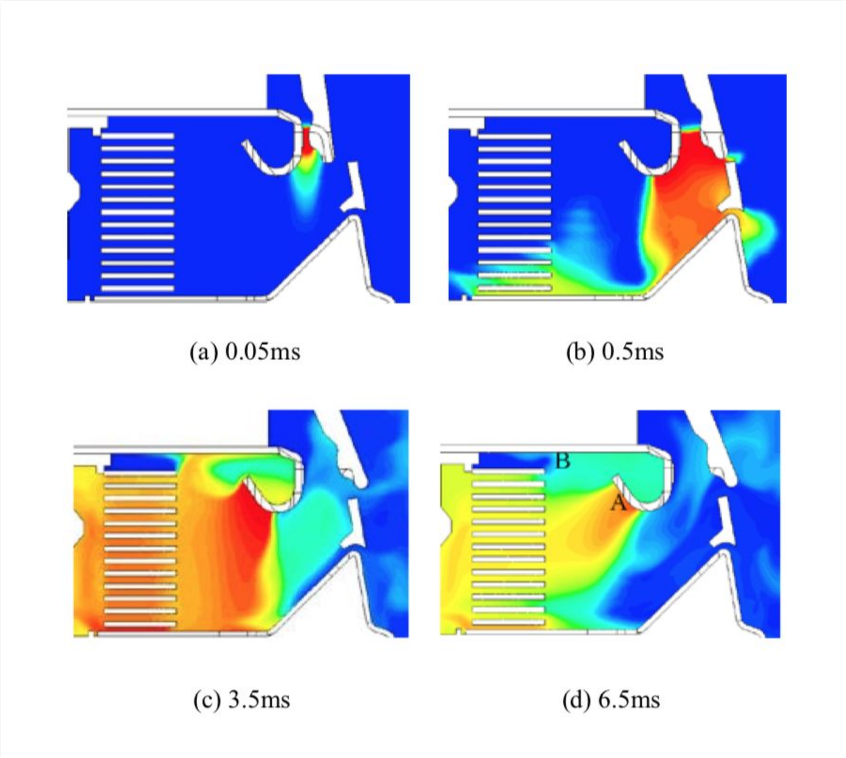
Main Goals

- Development of the finite-element model of the electric arc between two contacts with and without the ferromagnetic plate

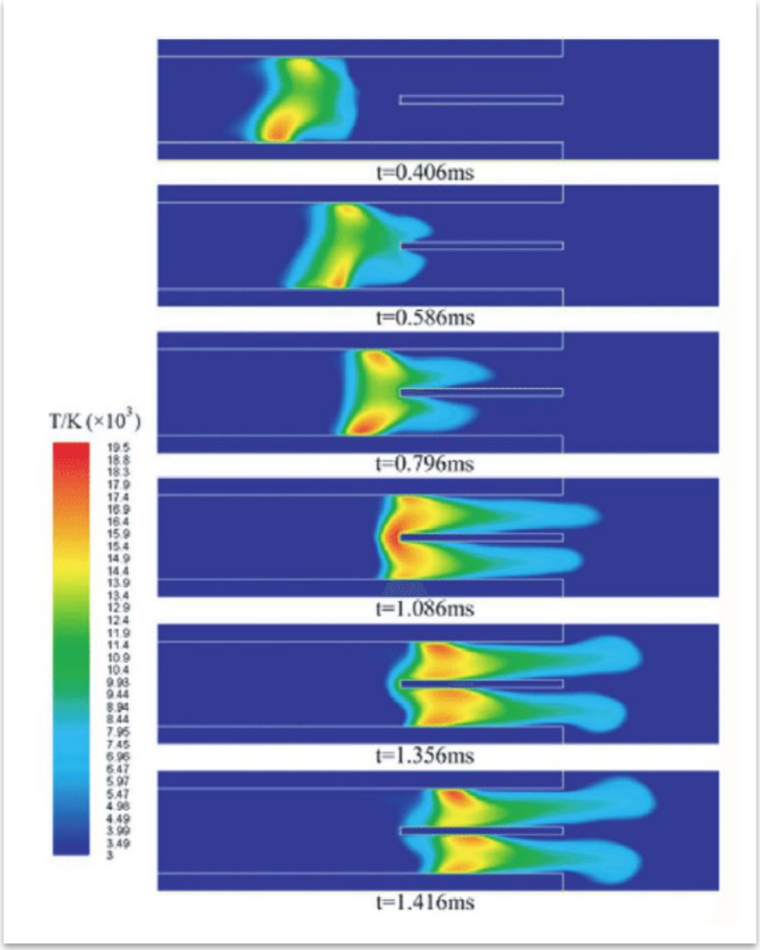
- Simulation of the low-voltage DC arc model for two cases

- Studying the dynamics of the arc propagation in the external magnetic field

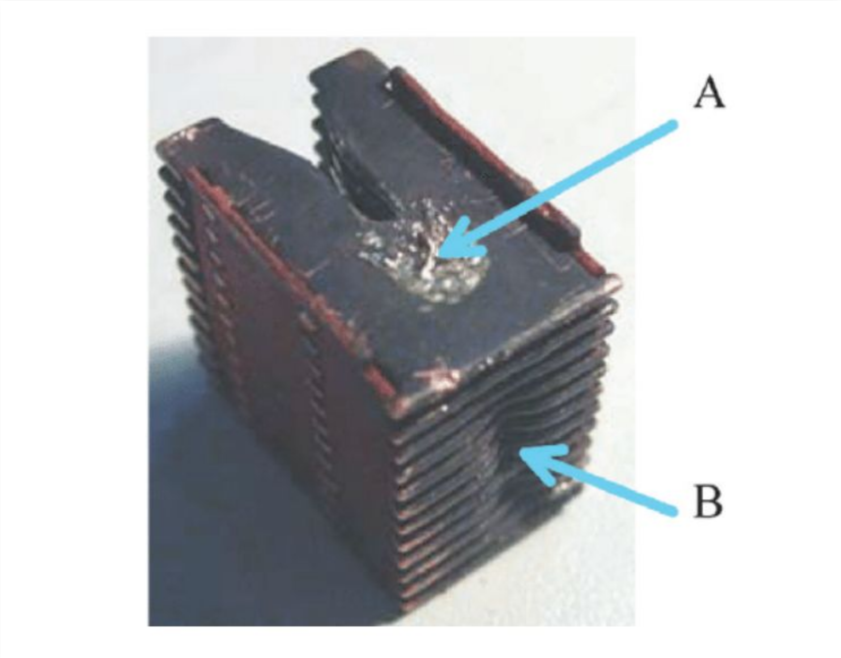
Relevance of the problem



Temperature distribution in the quenching chamber of the miniature circuit breaker

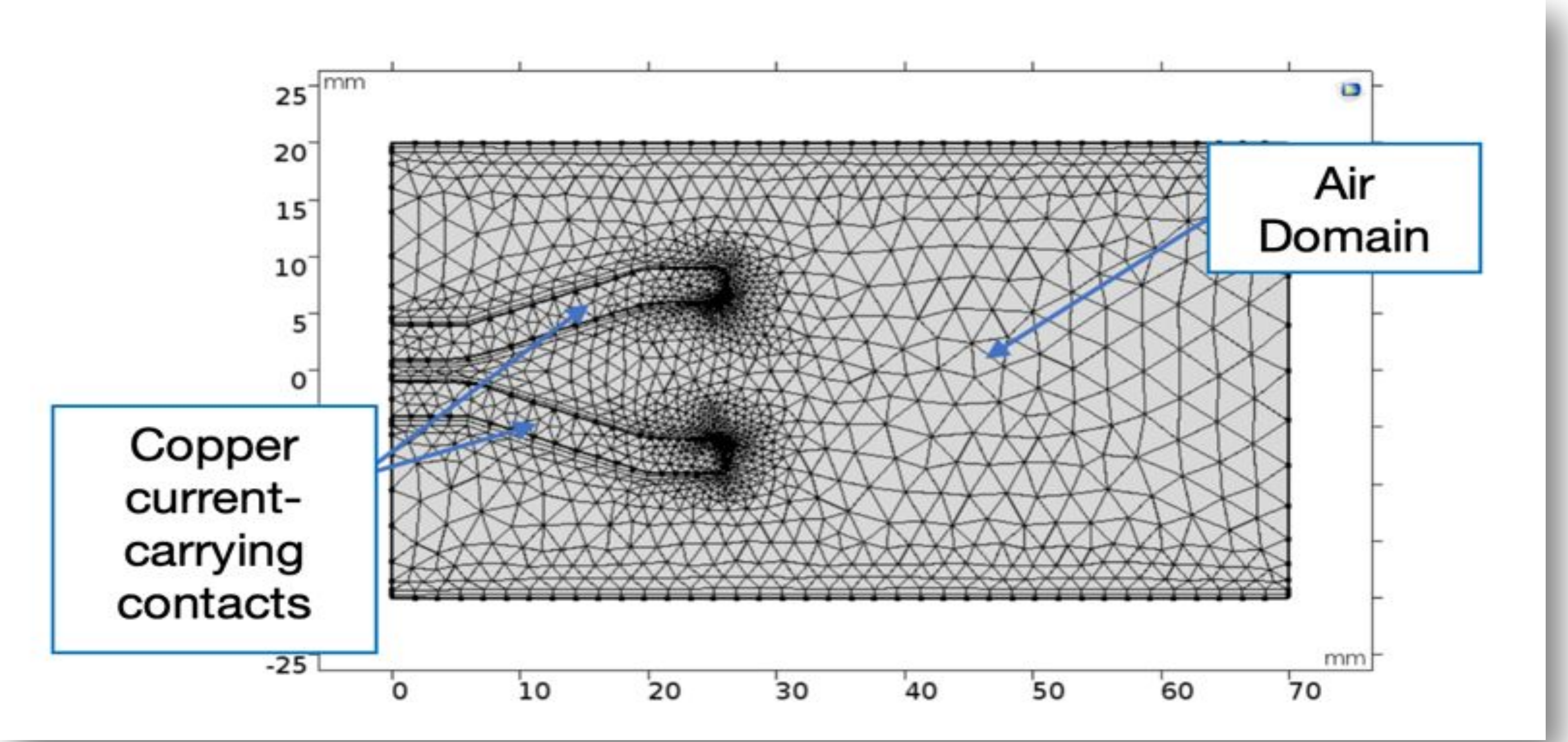


Arc temperature distribution sequence on the symmetry plane of the chamber



Erosion of splitter plates in a low-voltage circuit breaker.
The most strongly eroded regions are marked as A and B

Geometry, materials, finite-element mesh of the DC arc model without the ferromagnetic plate



The Electric Currents physics interface formulates the problems in terms of the Electric Scalar Potential – V

$$\mathbf{E} = -\nabla V$$

$$\mathbf{D} = \varepsilon_0\mathbf{E} + \mathbf{P}$$

$$-\nabla\cdot\frac{\partial}{\partial t}(\varepsilon_0\nabla V - \mathbf{P}) - \nabla\cdot(\sigma\nabla V - \mathbf{J_e}) = Q_{J,V}$$

$$\nabla\cdot\mathbf{J} = Q_{J,V}$$

The Magnetic Fields physics interface formulates the problems in terms of the Magnetic Vector Potential – **A**

$$\mathbf{H} = \frac{1}{\mu_0}\mathbf{B} - \mathbf{M}$$

$$\mathbf{E} = -\frac{\partial(\mathbf{A_b} + \mathbf{A_r})}{\partial t}$$

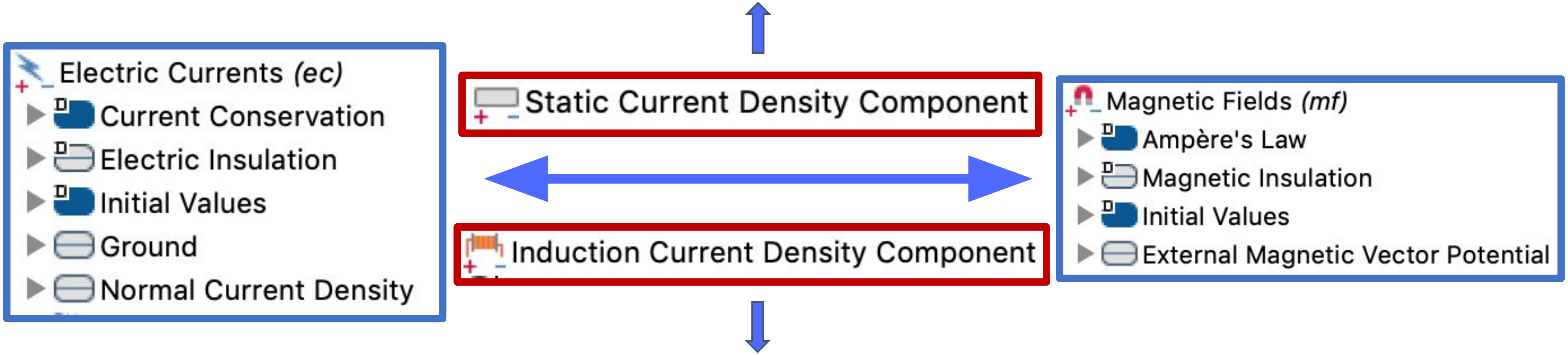
$$\nabla\times\left(\frac{1}{\mu_0}\nabla\times(\mathbf{A_b} + \mathbf{A_r}) - \mathbf{M}\right) + \sigma\frac{\partial(\mathbf{A_b} + \mathbf{A_r})}{\partial t} - \sigma\mathbf{v}\times\left(\nabla\times(\mathbf{A_b} + \mathbf{A_r})\right) = \mathbf{J_e}$$

$$\nabla\times\mathbf{H} = \mathbf{J}$$

$$\mathbf{B} = \nabla\times(\mathbf{A_b} + \mathbf{A_r})$$

Physics interfaces and multiphysics

$$\mathbf{J}_{\mathrm{e,mf}} = -\sigma \nabla V \qquad \mathbf{J}_{\mathrm{mf}} =- -\sigma \frac{\partial \mathbf{A}}{\partial \mathrm{t}} + \mathbf{J}_{\mathrm{e,mf}}$$



$$\mathbf{J}_{\mathrm{ec}} = -\sigma \nabla V + \mathbf{J}_{\mathrm{e,ec}} \qquad \mathbf{J}_{\mathrm{e,ec}} = -\sigma \frac{\partial \mathbf{A}}{\partial \mathrm{t}}$$

Physics interfaces and multiphysics

Heat Transfer in Fluids (ht)
- Fluid
- Initial Values
- Thermal Insulation
- Solid
- Temperature

Flow Coupling

Temperature Coupling
Temperature Coupling

Laminar Flow (spf)
- Fluid Properties
- Initial Values
- Wall
- Gravity
- Open Boundary
- Volume Force

$$D_z \rho C_p \frac{\partial T}{\partial t} + d_z \rho C_p \mathbf{u} \cdot \nabla T + \nabla \cdot \mathbf{q} = d_z Q + q_0 + d_z Q_p + d_z Q_{vd}$$

$$\rho \frac{\partial \mathbf{u}}{\partial t} + \rho(\mathbf{u} \cdot \nabla)\mathbf{u} = \nabla \cdot \left[-p\mathbf{I} + \mu\left(\nabla \mathbf{u} + (\nabla \mathbf{u})^T\right)\right] + \mathbf{F} + \rho \mathbf{g}$$

$$\rho \nabla \cdot (\mathbf{u}) = 0$$

$$\mathbf{q} = -d_z k * \nabla T$$

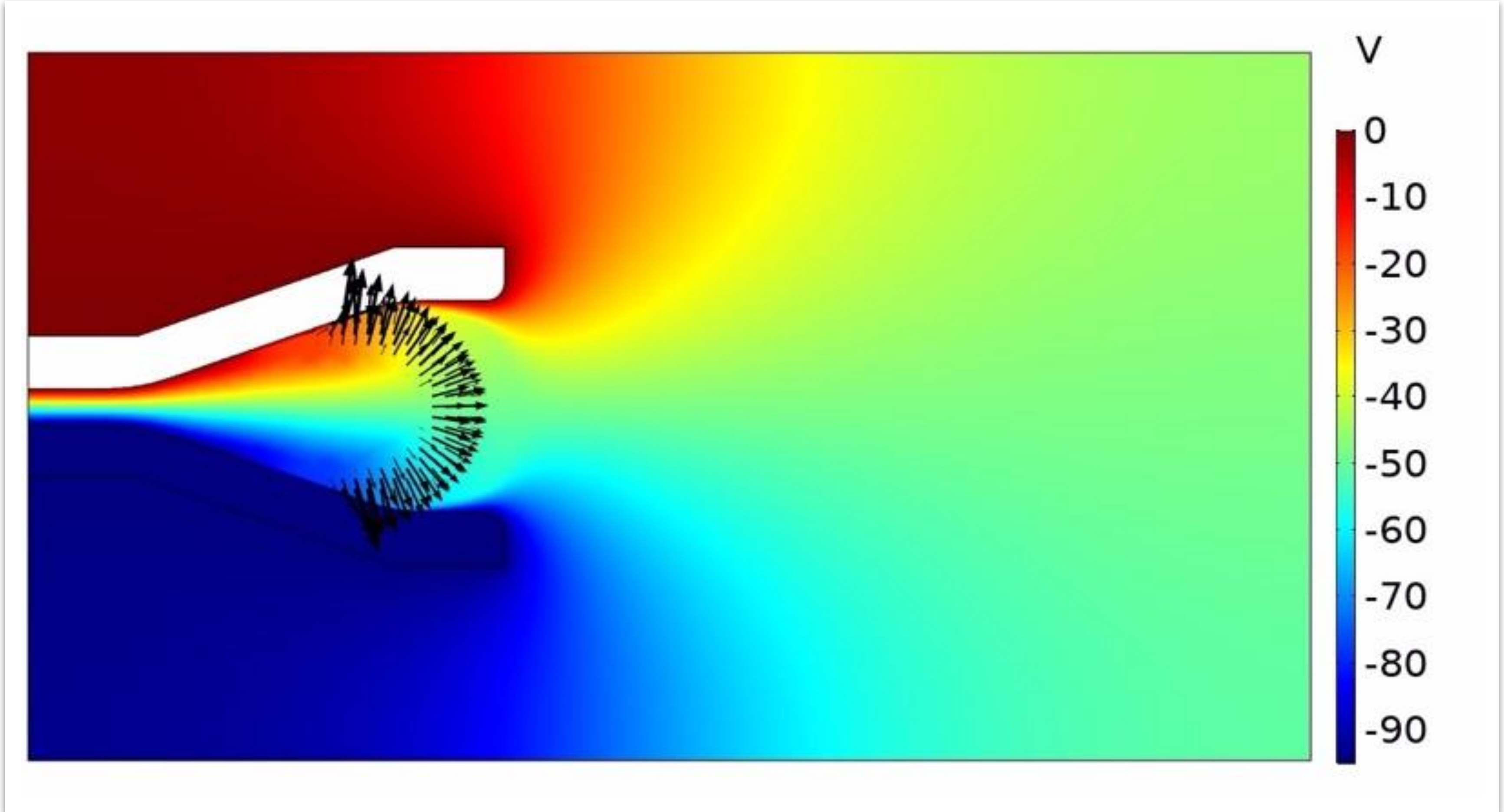
Volume force:

F	mf.Jy*mf.Bz	x	N/m³
	-mf.Jx*mf.Bz	y	

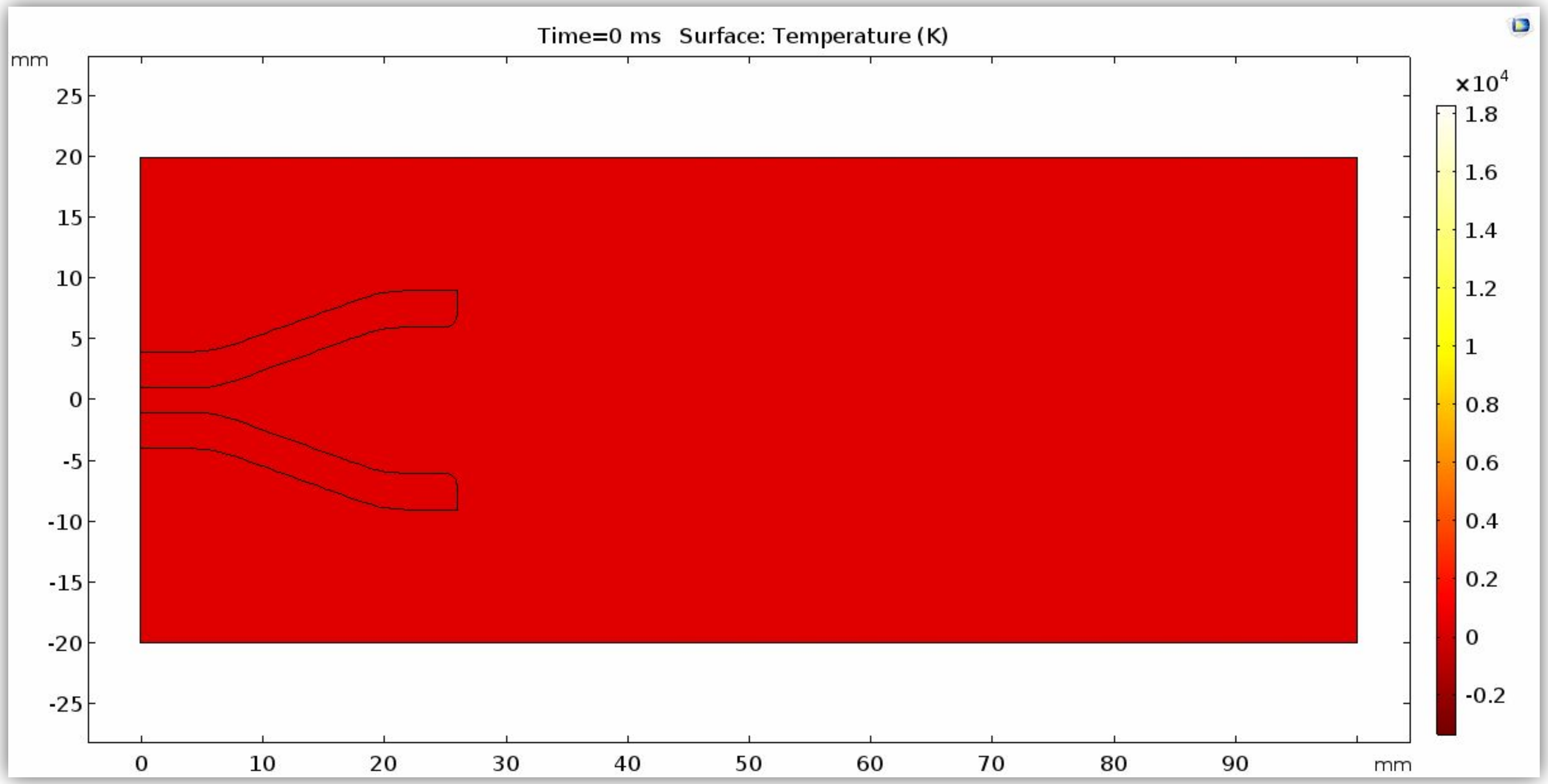
Lorentz force

Simulation results

Electric potential distribution at time 2 ms of the DC arc model without the ferromagnetic plate

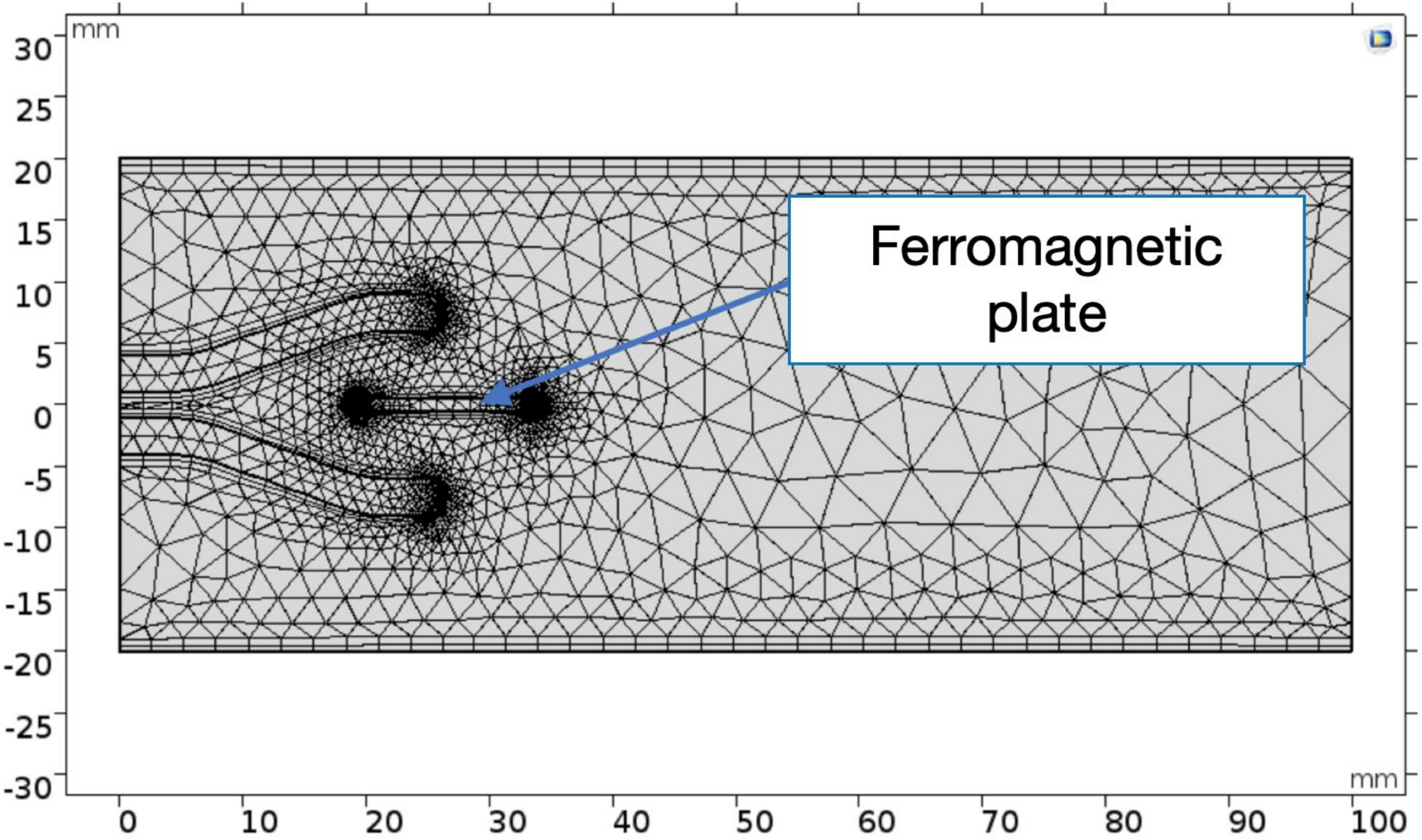


The dynamics of the arc propagation in the external magnetic field without the ferromagnetic plate.

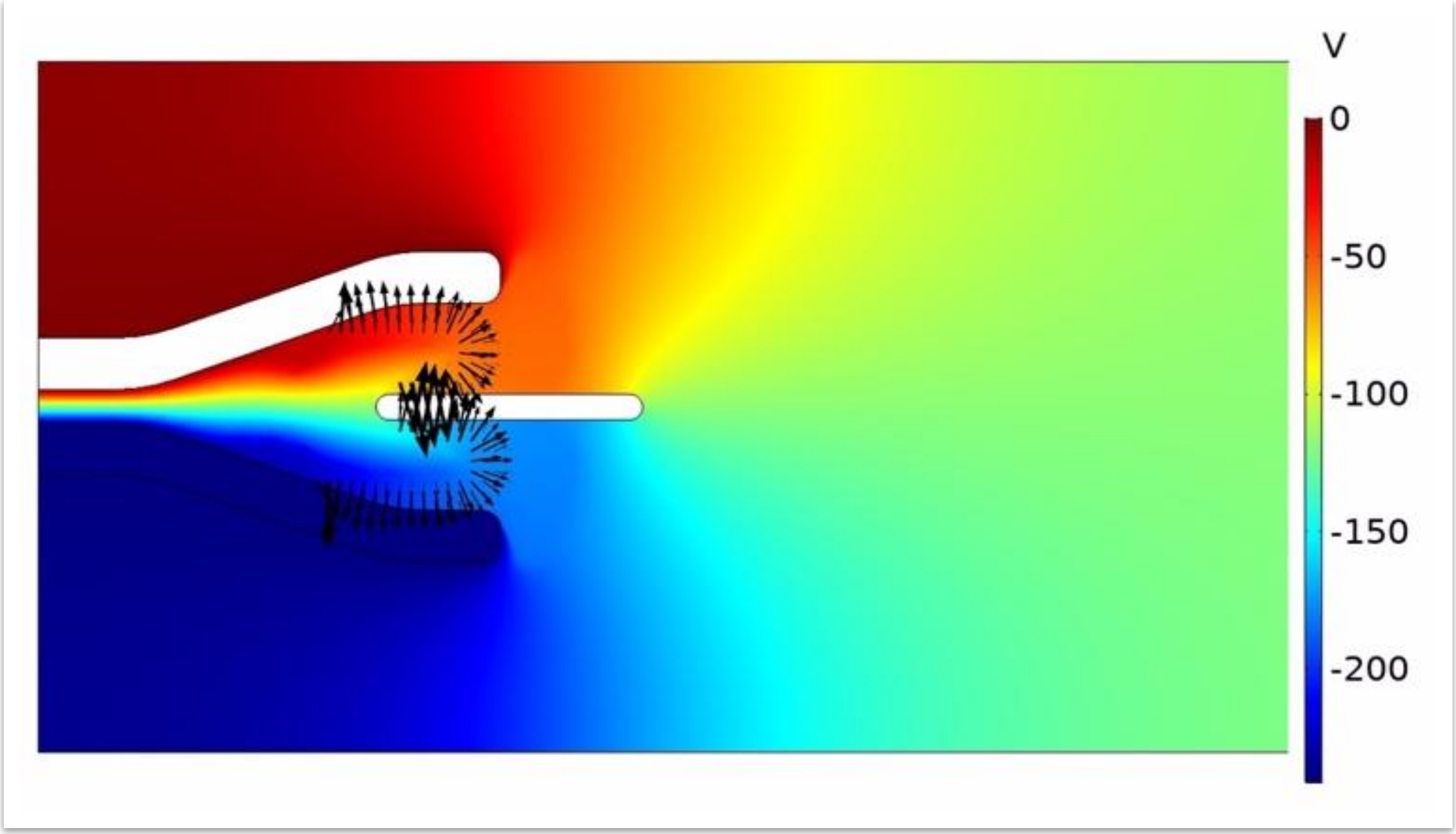


Temperature distribution animation

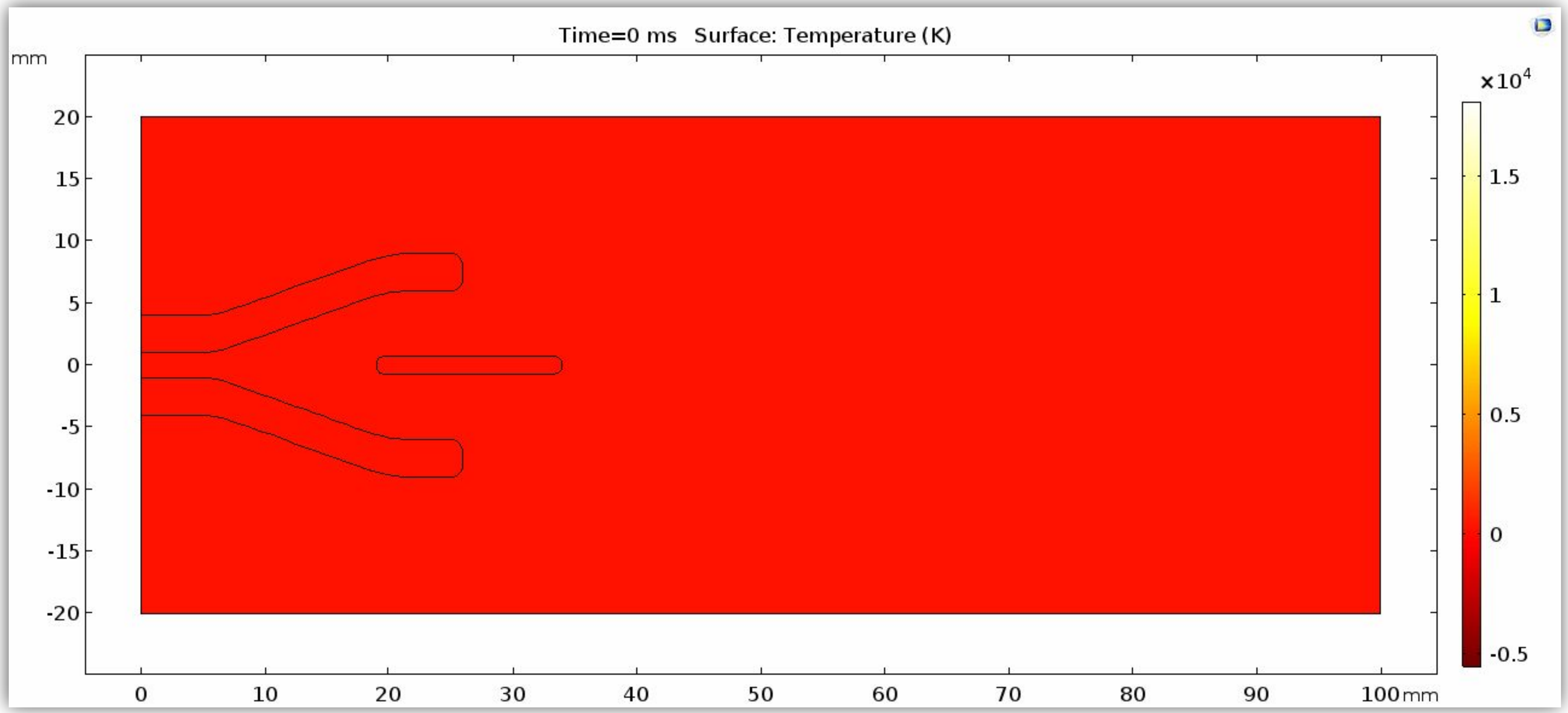
Geometry, materials, finite-element mesh of the DC arc model with the ferromagnetic plate



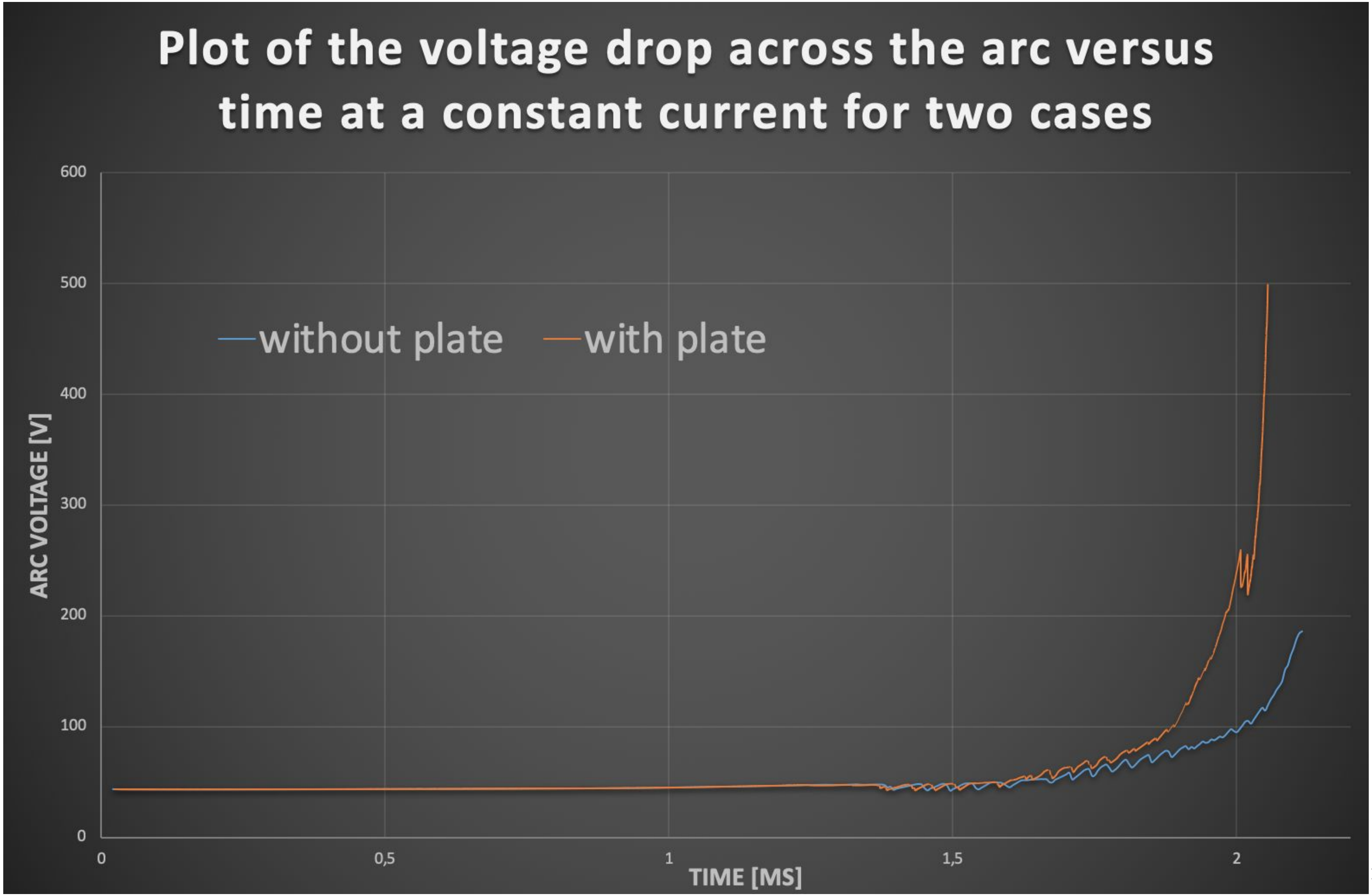
Electric potential distribution at time 2 ms of the DC arc model with the ferromagnetic plate



The dynamics of the arc propagation in the external magnetic field with the ferromagnetic plate.



Temperature distribution animation


Plot of the voltage drop across the arc versus time at a constant current for two cases
without plate
with plate
ARC VOLTAGE [V]
600
500
400
300
200
100
0
0
0,5
1
1,5
2
TIME [MS]

Conclusions

- Two complex finite-element multiphysics models of the low-voltage DC arc between two contacts were built in COMSOL Multiphysics

- Simulations for the cases with and without the ferromagnetic plate were performed

- The dynamics of the propagation of the arc in the external transverse magnetic field was studied

Thank you!

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