# Three-Dimensional Numerical Simulation of Arc Motion Between Bus-Bar Electrodes

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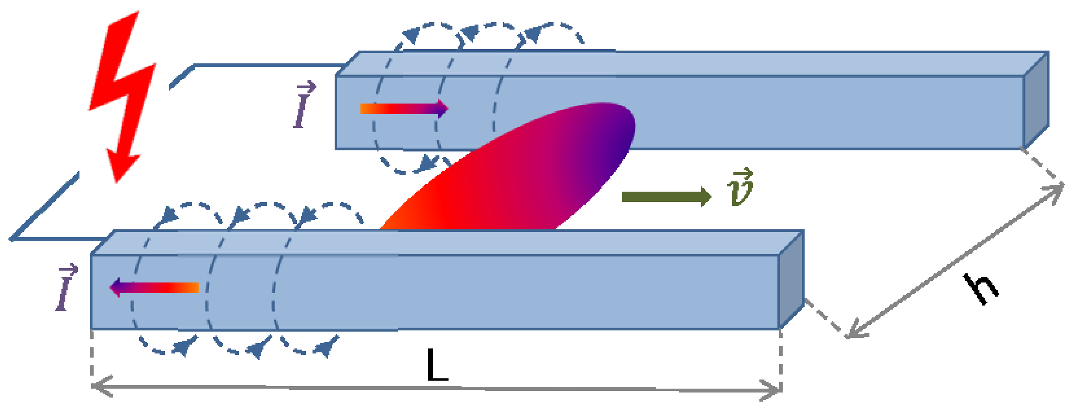
## Introduction

In this work, numerical simulations of the electric arc displacement along bus-bar electrodes are performed by means of COMSOL Multiphysics® [1]. The interface "Equilibrium Discharge" is used in order to establish the arc model. It combined with "Heat Transfer" and "Electrical Currents" modules, which are used to describe the electrodes. Then, the arc displacement along the electrodes is implemented with the help of an ODE interface.

## Problematic

- Bus-bars electrodes geometrical construction are commonly used in aeronautical applications. The length of interest ranges from L~100 to 200 mm with an electrode gap of h ~ 10 mm.
- Generally voltage source AC or DC are used which provides a currents ranging from 100 to 1000 A. Pressure range is 0.1 to 1 atm.




In case of a fault, an electric arc takes place and propagates along the electrodes.

**Goal: To perform numerical simulations of the arc displacement.**

## Complications for the numerical simulations:

- Wide temperature range from 300 to 21 000 K;
- Thermodynamic properties and transport coefficients are non-linear functions of temperature;
- System of PDE is time-dependent and non-linear; the couplings between equations are non-linear as well;
- Relatively large calculation domain to resolve magnetic field around the electrodes.

## Conclusions

The numerical model of the electric arc has been established in COMSOL Multiphysics®. The calculation results show a good agreement with the experiments. The model allows us to predict the arc behavior for other conditions.
The reasonable calculation time is a good advantage of the model.

## Numerical model

The system of MHD equations describing the bulk plasma assumed in LTE. For the time-dependent and a subsonic laminar flow, this system of equations is:

solved in the plasma domain

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \rho \boldsymbol{v} = 0,$$

$$\frac{\partial \rho \boldsymbol{v}}{\partial t} + \nabla \cdot (\rho \boldsymbol{v} \otimes \boldsymbol{v}) = -\nabla \cdot \boldsymbol{I}p + \nabla \cdot \eta \hat{\pi} + \boldsymbol{j} \times \boldsymbol{B},$$

$$\rho C_p \left( \frac{\partial T}{\partial t} + \boldsymbol{v} \cdot \nabla T \right) = \nabla \cdot \left( \lambda \nabla T + \frac{5 k_b}{2e} \boldsymbol{j} \, T \right) + \boldsymbol{j} \cdot \boldsymbol{E} - Q_{rad},$$

$$\nabla \cdot \boldsymbol{j} = 0, \text{ where } \boldsymbol{j} = \sigma \boldsymbol{E},$$

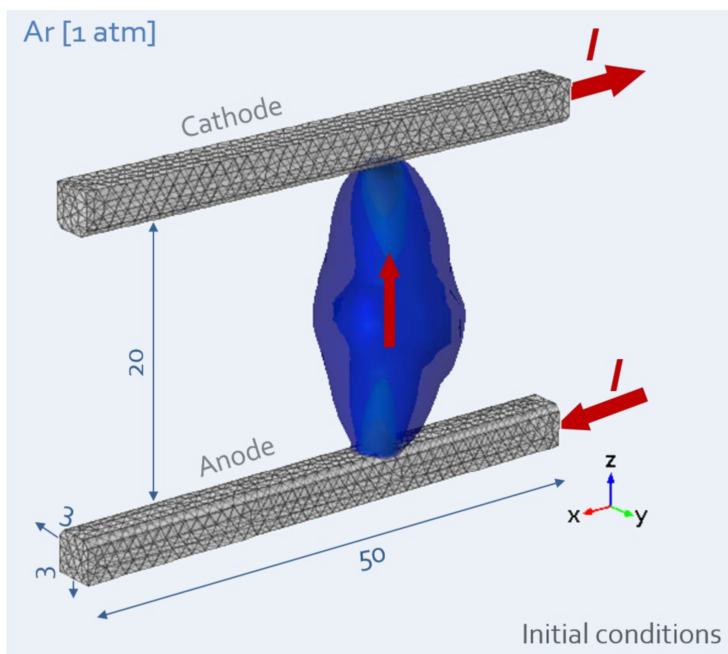
$$\nabla \times \frac{1}{\mu \mu_0} \boldsymbol{B} = \boldsymbol{j}, \qquad \boldsymbol{B} = \nabla \times \boldsymbol{A}.$$

$$\rho_{Cu} C_{p\,Cu} \frac{\partial T}{\partial t} - \nabla \lambda_{Cu} \nabla T = \frac{\boldsymbol{j}^2}{\sigma_{Cu}}$$

$$\nabla \cdot \boldsymbol{j} = 0$$

solved in the electrodes

Arc current is 200 A (DC);
Pressure 1atm;
Gas Argon.



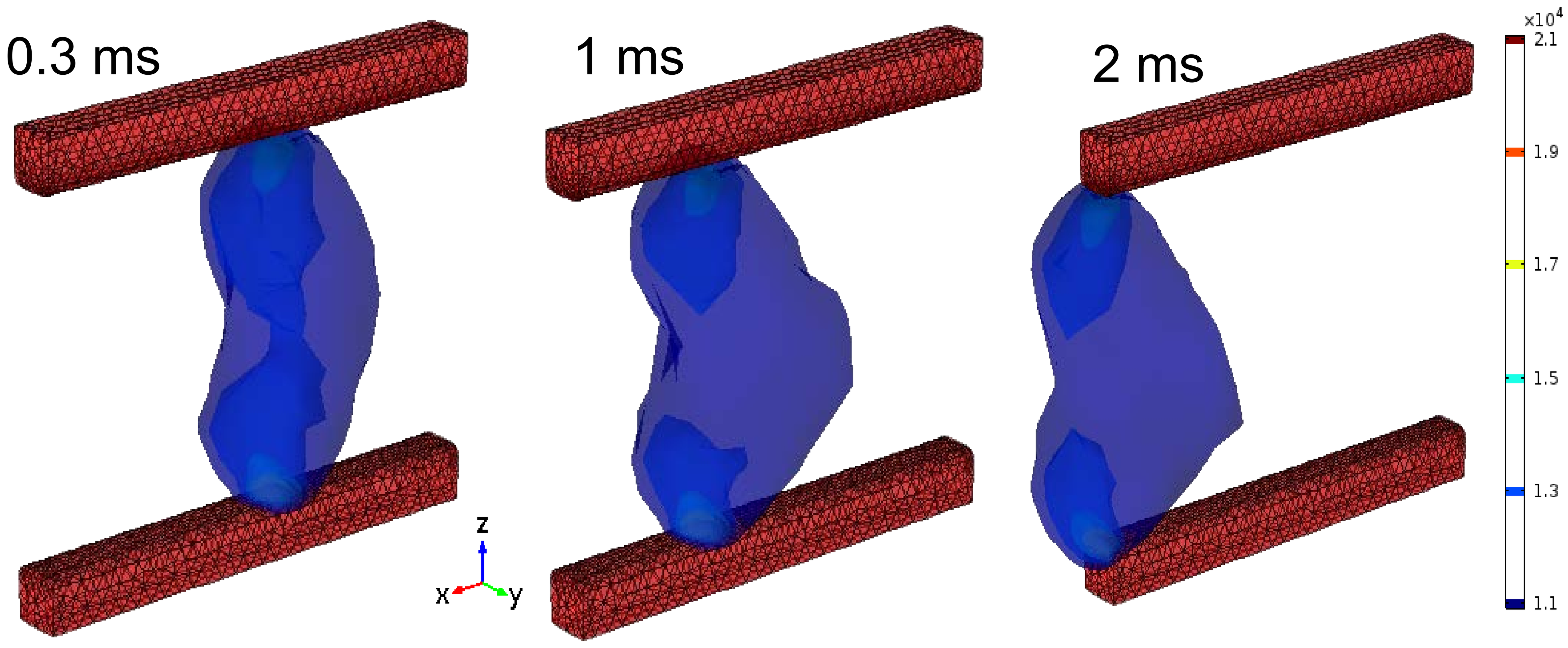

**Plasma-cathode interaction:**
•Spot mode with $R_{cs}$ = 1.5 mm [2] and $T_{cs}$ = 1000 K

**Plasma-anode interaction:**
•Spot mode with $R_{cs}$ = 1.5 mm heat flux $q_a = -j_n U_h$ ($U_h$ = 6 V)

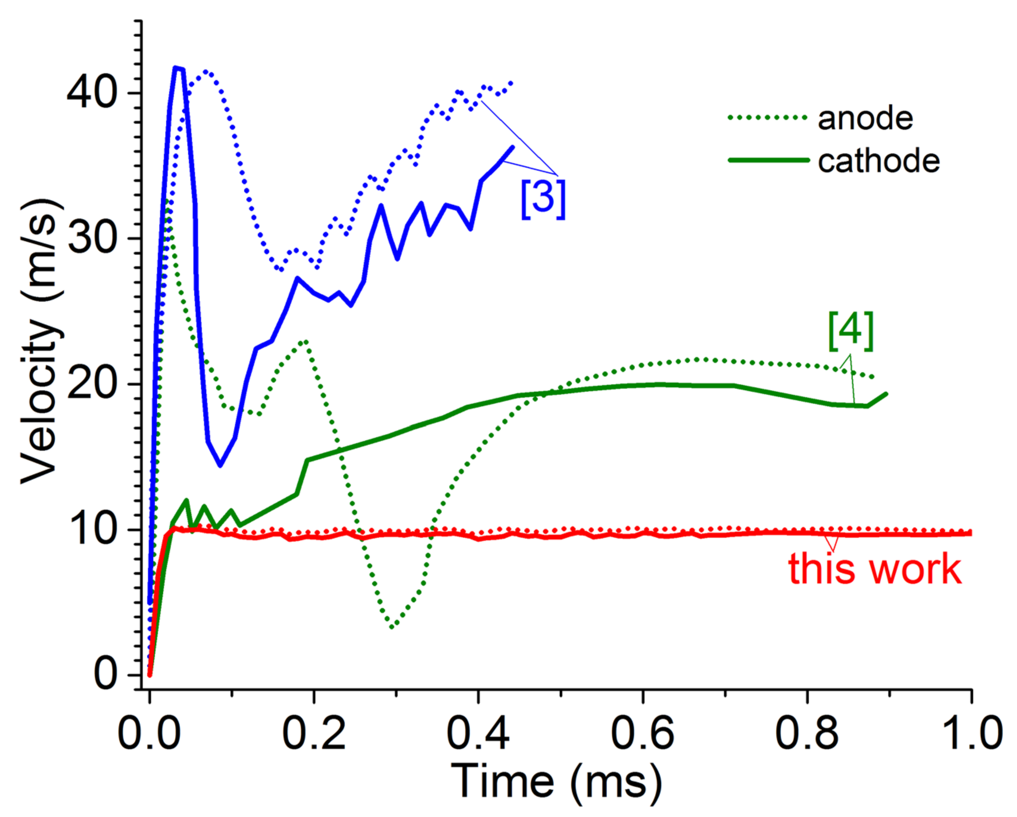
**Arc attachments displacement** is realized applying momentum concervation: Lorentz force, pressure gradient and drag forces ($\sim CV^2_{spot}$ where C is drag constant, $V_{spot}$ is attachment velocity) are taken into account to calculate attachments velocity.

## Results

Temperature distributions in the arc (in K) at the different time moments. The cathode and anode jets are developed and move with the same velocity about 10 m/s.
Similar results have been obtained on the experiment, when the arc speed is in the range 5-20 m/s for the current 200 A.




Arc velocity. Comparison with existed works




## Numerical realization:

- Number of elements $10^6$;
- Free tetrahedral mesh with mesh improvement near the electrodes (minimum element size 0.4 mm);
- Discretization order: first for hydrodynamic and heat transfer equations and second for electro-magnetic simulations;
- Segregated solver with condition to achieve relative tolerance 0.01.
- Calculation time: 1 week (Intel Xeon® 3.00GHz (2proc), 32 Go).

## References:

[1] COMSOL Multiphysics® reference guide, 2017.
[2] M. S. Benilov and A. Marotta, "A model of the cathode region of atmospheric pressure arcs" J. Phys. Appl. Phys., vol. 28, 1995.
[3] M.Lisnyak, M. Chnani, A. Gautier, J-M. Bauchire, "Behavior of a short electric arc between plane electrodes:numerical and experimental study", contributions to ICPIG congress, July 2017, Lisbon, Portugal
[4] B. Swierczynski, J. J. Gonzalez, P. Teulet, P. Freton, and A. Gleizes, "Advances in low-voltage circuit breaker modelling," 2004.

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