Simulation of an impulse arc discharge in line lightning protection devices.

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1. Introduction

In recent years line lightning protection devices (LLPD) based lightning protection devices have succeeded in lightning protection of overhead power lines. The example of multi-chamber based lightning protection device is depicted in Fig.1. In general LLPD consists of a large number of series connected chambers. The example of discharge chamber is given in Fig.2 and Fig3. Each electrode consists of two nested tubes – inner and outer tube. While the outer tube is constantly copper the material of inner tube can be copper, steel or tungsten. During normal grid operation, the device works as an insulator since the voltage over the device is insufficient to cause dielectric breakdown and arcing. Under the lightning overvoltage electrical breakdown occurs in every single chamber resulting in impulse current flowing through the LLPD. Initiated arc discharge causes erosion of the electrode material and chamber wall evaporation due to arc-wall interaction which leads to intensive pressure buildup, plasma outflow and eventually to arc extinction.

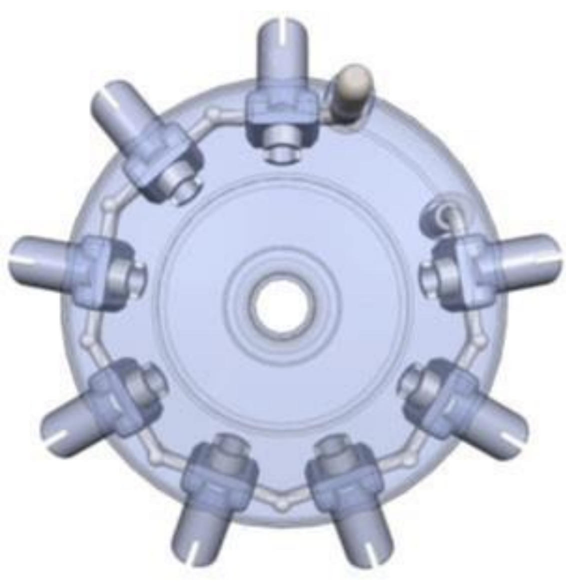


Figure 1. LLPD sample.

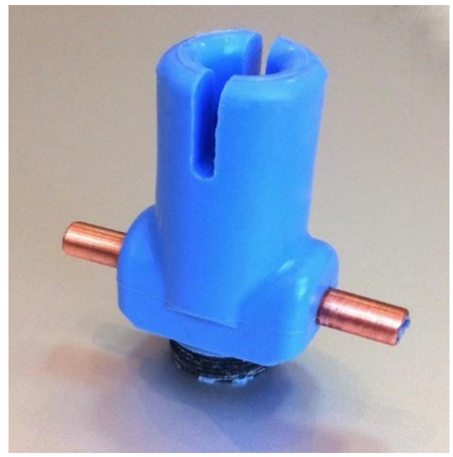


Figure 2. Discharge chamber.

Experimental investigations allowed to discover that certain chamber designs perform arc interruption with more efficiency meaning that geometry optimization is possible. Since pure empirical approach for solving optimization problem poses severe requirements on time consumption and investment method of

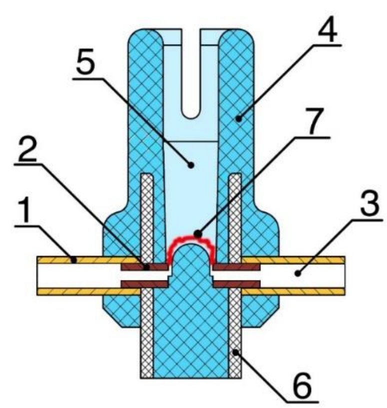


Figure 3. Design of discharge chamber of multi-chamber arrester: 1 – outer tube, 2 – inner tube, 3 – cavity, 4 silicone rubber, 5 – discharge slot, 6 – fiber-glass plastic sleeve, 7 – arc

numerical experiment was employed to look for better chamber design.

2. Basic Equations

In order to simplify the model and emphasize the most important processes involved several assumptions were made:

1. The flow is laminar
2. The plasma is in Local Thermodynamic Equilibrium (LTE), i.e. electron and heavy particles have the same temperature
3. Thermodynamic properties only depend on temperature
4. The influence of magnetic forces
5. The influence of electrode erosion and material ablation is taken into account

In case of LTE General approach to arc simulations relies on MHD equations:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \boldsymbol{u}) = 0 \qquad (1)$$

$$\frac{\partial (\rho \boldsymbol{u})}{\partial t} + \nabla \cdot (\rho \boldsymbol{u} \otimes \boldsymbol{u}) = -\nabla p + \nabla \cdot \hat{\boldsymbol{\tau}} + [\mathbf{j} \times \mathbf{B}] \quad (2)$$

$$\frac{\partial (\rho \boldsymbol{h})}{\partial t} + \nabla \cdot (\rho h \boldsymbol{u}) = \frac{\partial p}{\partial t} + \nabla \cdot (\hat{\boldsymbol{\tau}} \boldsymbol{u}) + \boldsymbol{j} \cdot \boldsymbol{E}$$
$$+ \nabla \cdot (\boldsymbol{q}_{\boldsymbol{cond}} + \boldsymbol{q}_{\boldsymbol{rad}}) \qquad (3)$$

Here, ρ represents the mass density of the plasma, the u is the gas own velocity, p is the static pressure, τ is the viscous part of the stress tensor, and h is the specific enthalpy. The last term of Eq. (26) represents the heat flux, which has been split into a heat conduction q and radiative heat flux q_{rad}. In order to solve the above set of equations, it necessary to add state equations,

$$\rho = \rho(T)$$

and

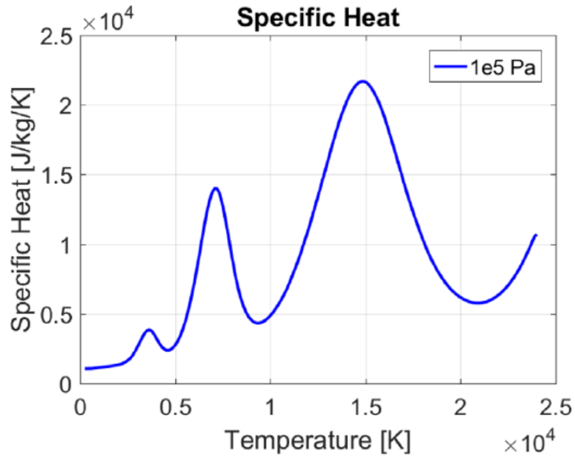
$$h = h(T)$$

Data for viscosity, heat conductivity, and the electric conductivity of the plasma is also needed. The coupling to the electromagnetic field is realized by ohmic heating **j** · **E**, where **j** is the electric current density, **E** is the electric field.

The influence of self-generated magnetic field **B** such as Lorentz force [**j** × **B**], was not considered for simplification. The current density in a conducting fluid is given by

$$\mathbf{j} = \sigma \mathbf{E} \qquad (6)$$

,where σ is the conductivity of the plasma.



3. Use of Comsol Multiphysics

The implementation of previously described MHD equations was made by coupling CFD and ACDC module, Laminar Flow and Electrical Currents correspondingly. To model the imposed lightning current Terminal boundary condition was applied to oe of the electrode's edge. The analytic function describing the current pulse is depicted on Fig.5.

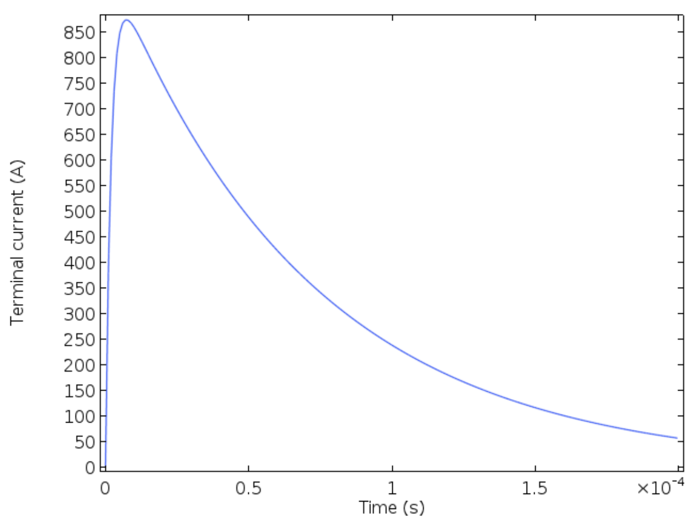


Figure 5. Lightning current pulse.

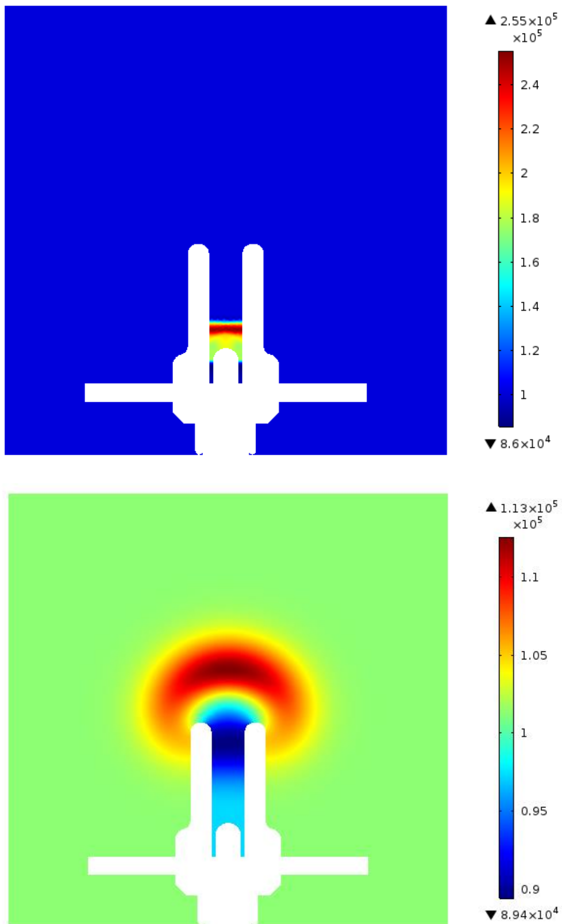


Figure 6. Pressure in discharge chamber #1 for 8 µs (top) and 100 µs (bottom)

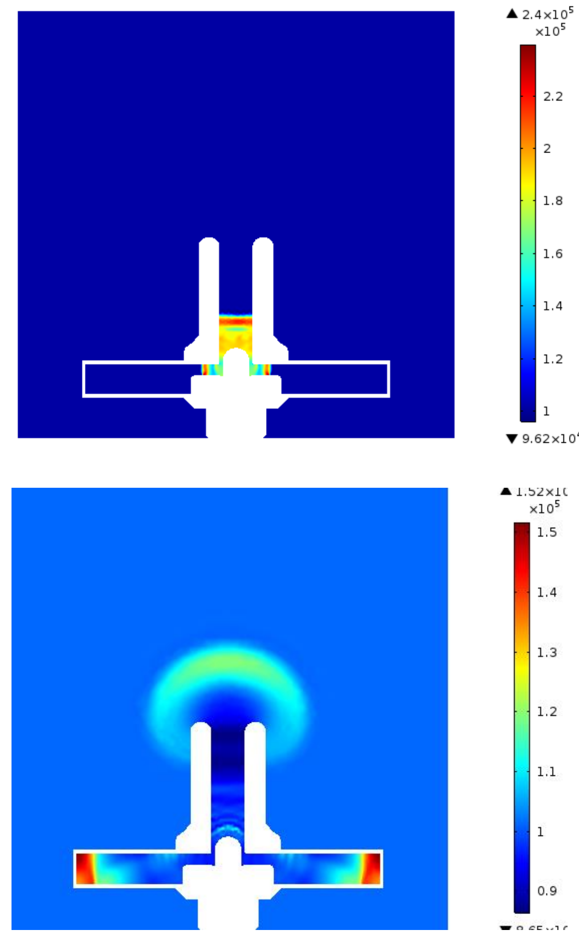


Figure 7. Pressure in discharge chamber #1 for 8 µs (top) and 100 µs (bottom)

The Ohmic heating is included by addition of Heat Source in Laminar Flow with Electromagnetic volumetric loss density set. Initial temperature up to 5000 K was set in the gap between electrodes meaning to model preheating of conducting channel during breakdown stage. The total duration of simulation was set to 200 µs which stands for typical duration of lightning pulse.

4. Results and Discussions

You may include color simulation images. Please export your simulation images such that the final resolution of your figures is at least 300dpi.

5. Conclusions

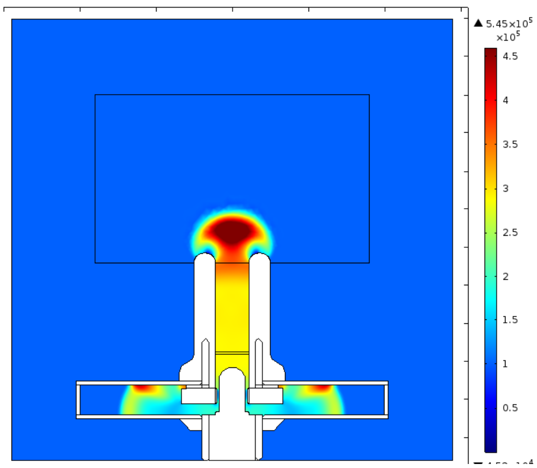
You may include any implications or conclusions obtained from your work. You may include plans for future work.

6. References

1. Author, Article title, *Journal*, **Volume**, page numbers (year)
2. Author, *Book title*, page numbers. Publisher, place (year)

Acknowledgements

You may include acknowledgements here.



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