Thermal analysis of a superconducting bus-bar for the SIS100 particle accelerator at FAIR

ŁUKASZ TOMKÓW

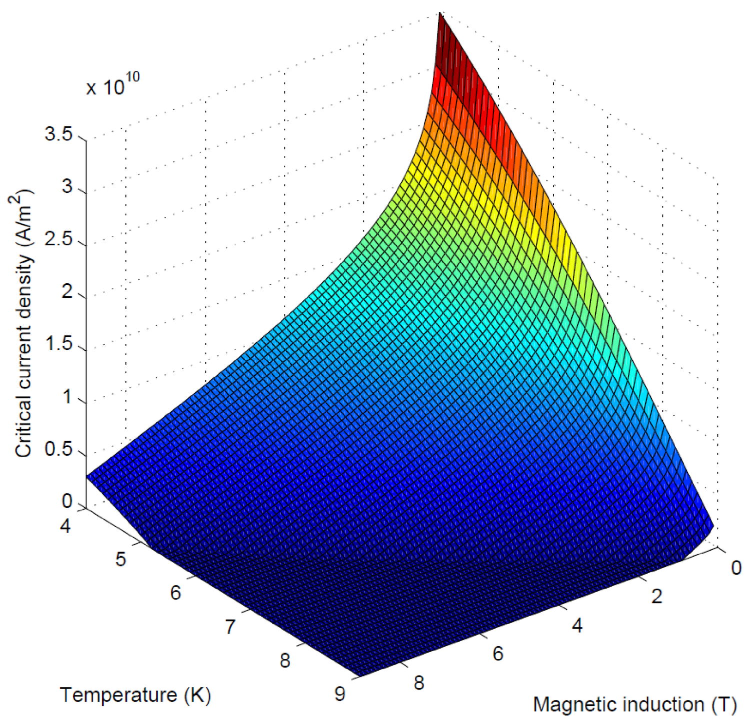
Wrocław University of Technology, Faculty of Mechanical and Power Engineering, Department of Cryogenic, Aviation and Process Engineering

Introduction

SIS100 is a superconducting accelerator for heavy ions, currently under construction by international FAIR collaboration in GSI Helmholtzzentrum für Schwerionenforschung in Darmstadt (Germany). By-pass lines connecting the sections of the superconducting magnets are designed at Wrocław University of Technology. They will be used to carry liquid helium and the electric current. The current will be transferred by four pairs of the bus-bars made of a Nuclotron-type cable containing NbTi.

The numerical analysis was performed to calculate the heat generation occurring in the bus-bar operating under the most demanding regime - fast ramping, triangular current with the frequency of 1 Hz and the maximum value of 13 kA. The coupled electromagnetic-thermal model was implemented in Comsol. Electromagnetic boundary conditions were found using static model. Thermal boundary conditions are based on heat transfer considerations of the entire by-pass line.

Critical surface



H-formulation

$\mu_0 \frac{\partial \mathbf{H}}{\partial t} + \nabla \times \mathbf{E} = 0$ - Faraday's law

$\mathbf{J} = \nabla \times \mathbf{H}$ - calculation of current density

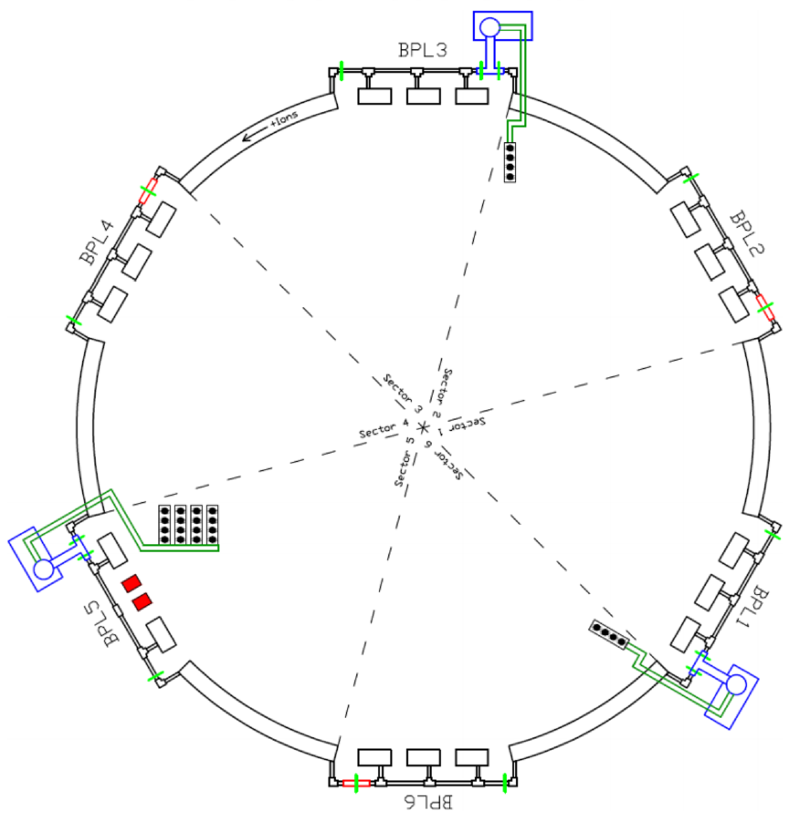
$E = \left(\frac{J - J_c}{J_c} \cdot \mathfrak{H}(J - J_c) \right)^n$ - non-linear electric field

$J_c = \frac{C_0}{B} b^\alpha (1-b)_1^\beta (1-t_r^t)^\gamma$ - critical current density

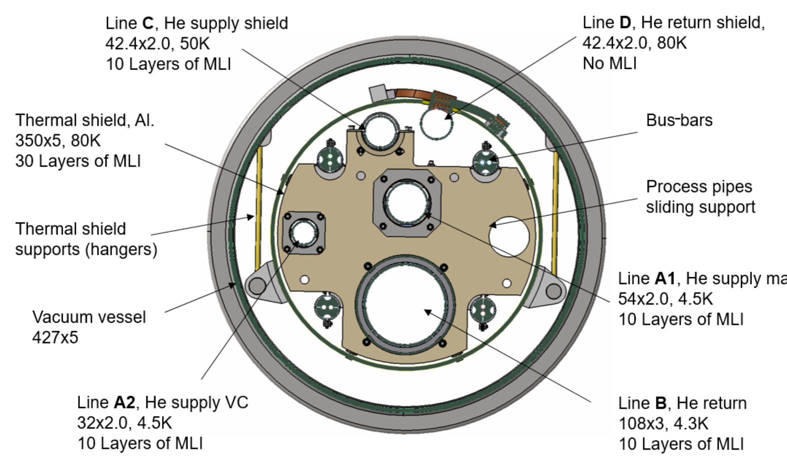
$q_g = \mathbf{j}_s \bullet \mathbf{E}$ - heat generation

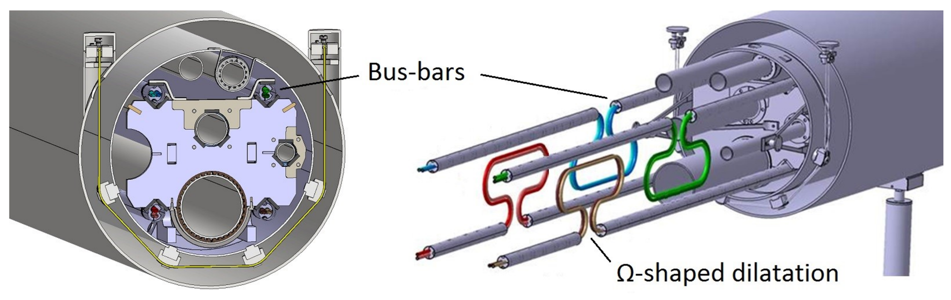
Analysed object

SIS100 Accelerator

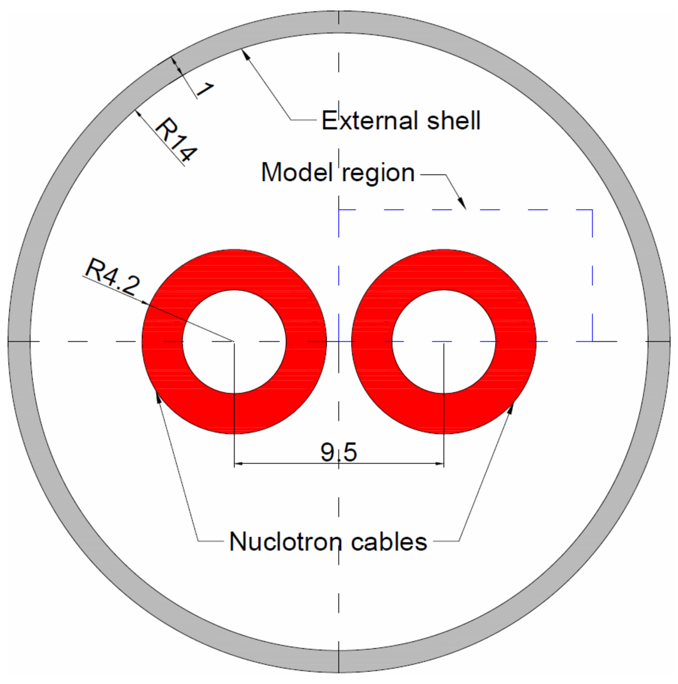


By-pass line (BPL)

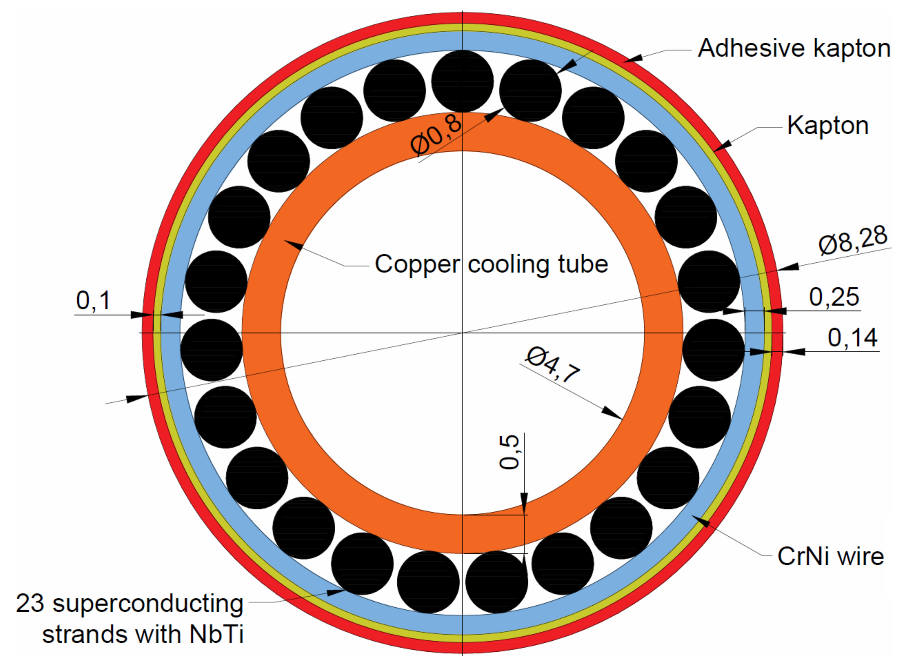




Superconducting bus-bar

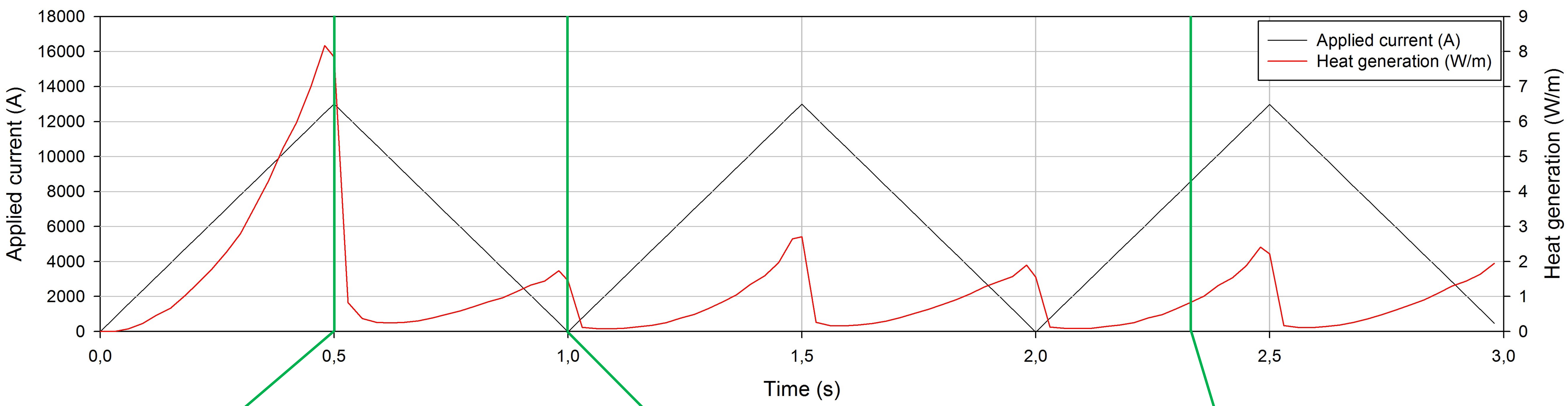


Nuclotron cable



- maximum calculated heat generation - 8.17 W/m during the initial current application
- average during the normal operation - 0.79 W/m, for all by-pass lines - 213 W
- roughly 5% of the total heat budget of the accelerator
- temperature increase due to the heat generation - less than 0.1 K
- very low risk of quench thanks to efficient cooling with two-phase liquid helium

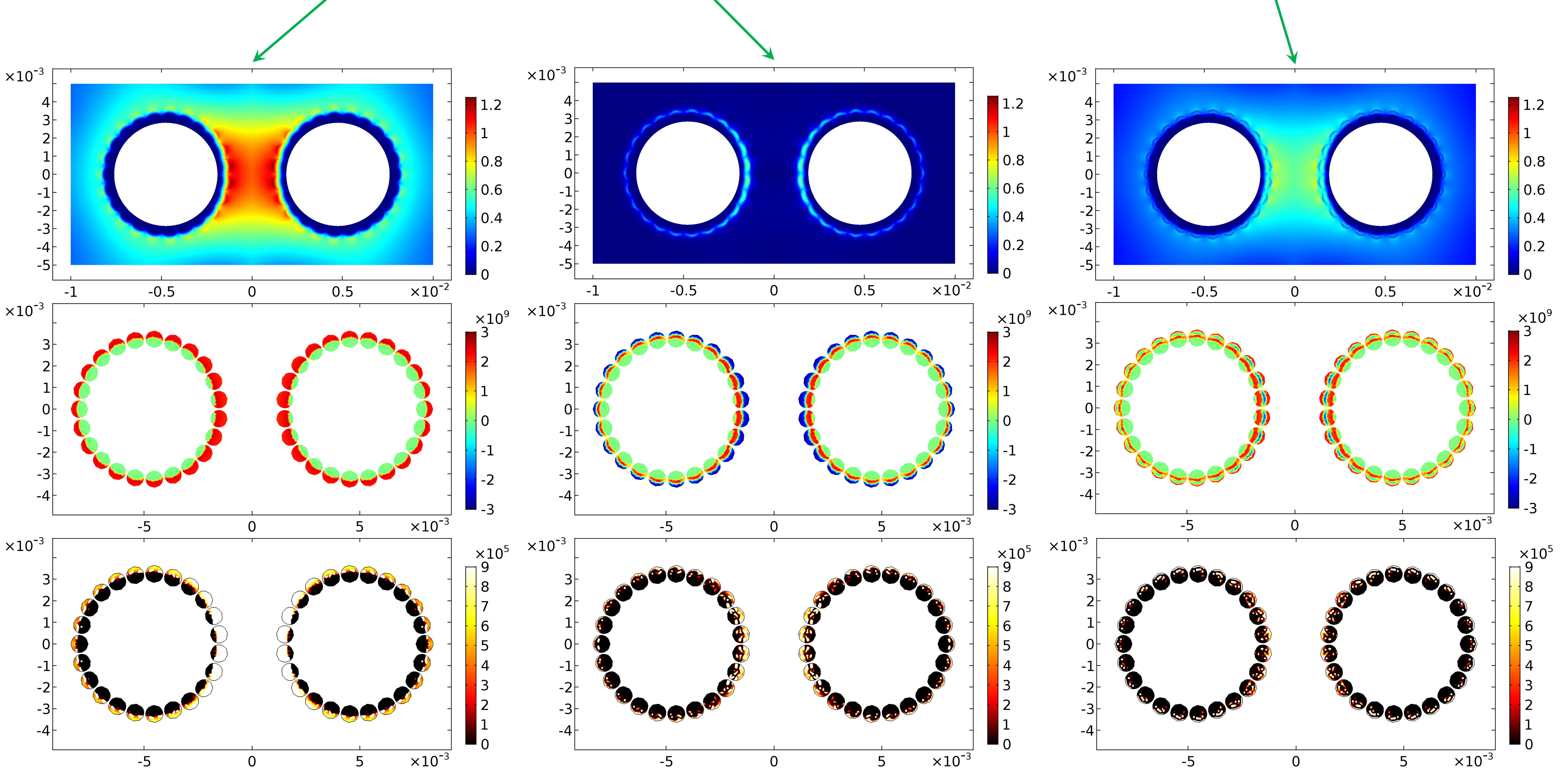
Heat generation and the applied current



Magnetic induction (T)

Electric current density (A/m²)

Heat generation (W/m³)



- maximum heat generation during the entire operation
- strands are filled with the current, an electric field and the heat generation appear everywhere, where the current is present
- sudden drop of the heat generation (almost to zero) after reversing the direction of the current change

- local peak in heat generation
- coexistence of two electric currents flowing in reverse directions
- frozen magnetic field visible in the superconducting strands
- total electric current carried by the bus-bar is zero

- appearance of the complex pattern of the electric currents
- losses occurring in the region where the current is changing, corresponding to outer edge of the cables
- numerical artifacts visible, small effect on total calculated power generation

E-mail: lukasz.tomkow@pwr.edu.pl; further reading: Łukasz Tomków, "Numerical modelling of superconducting components applied in the devices for high energy physics", doctoral thesis, Wrocław University of Technology