Models for optimization and AC Losses Analysis in a 2G HTS Cable

HTS 2020 Modelling
7th International Workshop on Numerical Modelling of High Temperature Superconductors
22nd – 23rd June 2021, Virtual (Nancy, France)

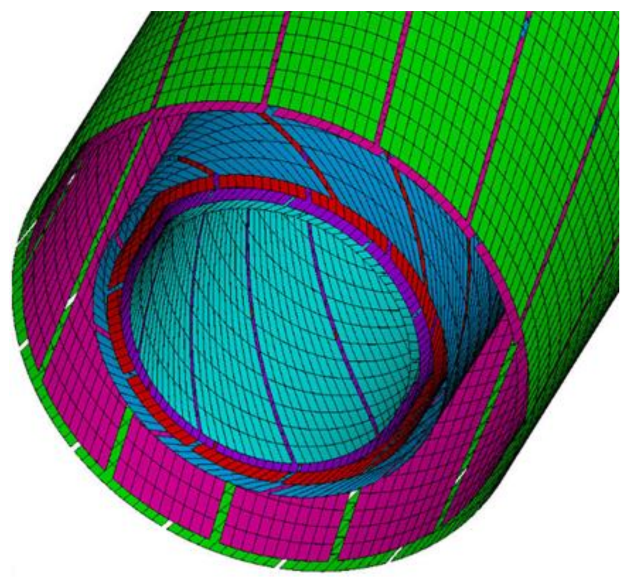
V. Zubko, S. Fetisov, S. Zanegin

Russian Scientific R&D Cable Institute, 5, sh. Entuziastov, Moscow, 111024, Russia

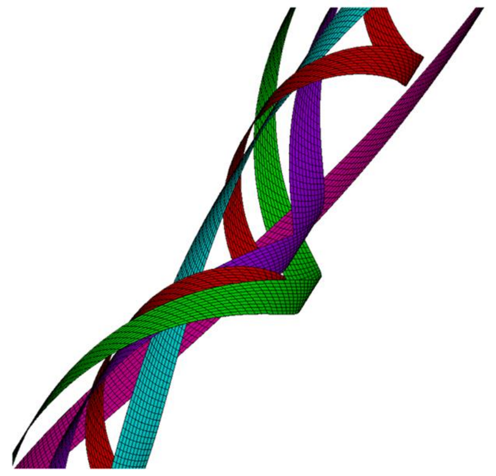
Background

Numerical methods can handle any geometrical configuration, time-dependent problems, and both linear and nonlinear cases.
The FEM models using the ANSYS Emag software to solve the transient electromagnetic problem for complex study (optimization and AC losses) of the 2G HTS cable were developed.
Two 3D FEM models were developed to optimize the geometry of both coaxial and triaxial 2G HTS cables. In addition, with the help of the 3D FEM model, we can calculate the hysteresis losses in a NiW substrate of 2G HTS tapes of the cable. The transient 2D FEM model was developed and used for the calculation of AC losses in the cables and stacks of 2G HTS tapes. For the correct calculation of the AC losses, it is important to determine the parameters in an empirical expression describing the critical current density of the 2G HTS tapes dependence from the vector magnetic field and its non-uniformity across the tape width.

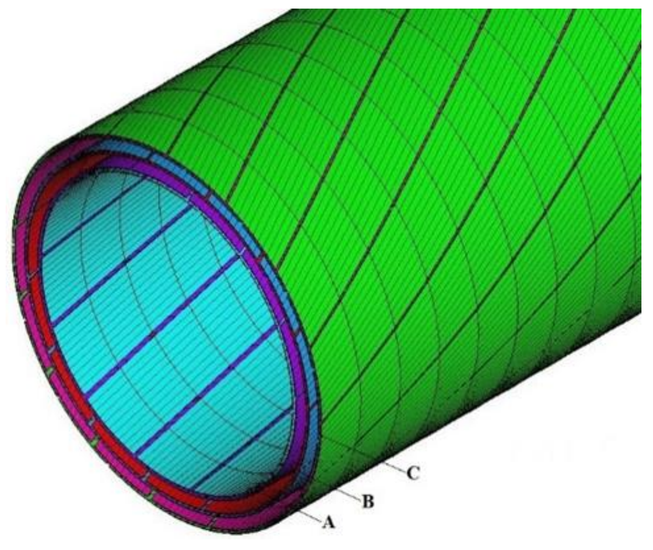
3D models for geometry optimization of the HTS cables



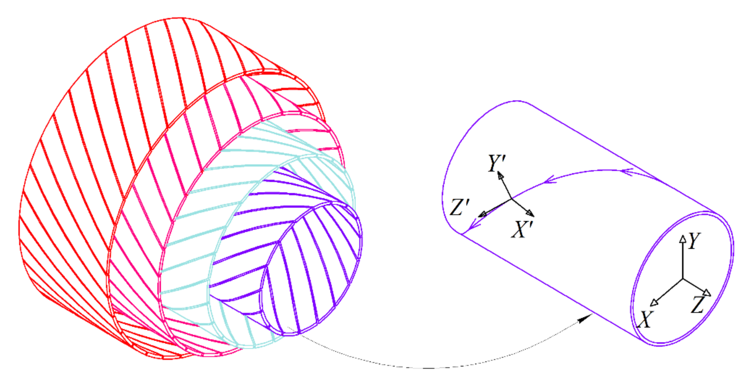
The elements of HTS layers of the tapes of end part of the coaxial cable (4-layer core and the 2-layer shield) in detailed 3D FEM model.



The elements of several tapes in layers of the cable.



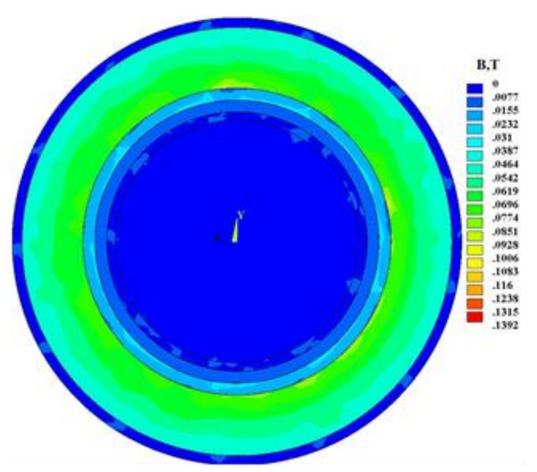
The mesh elements in the detailed 3D FEM model of the layers of HTS tapes on the end part of the triaxial cable. Letters A, B, C indicate the phases of the cable.



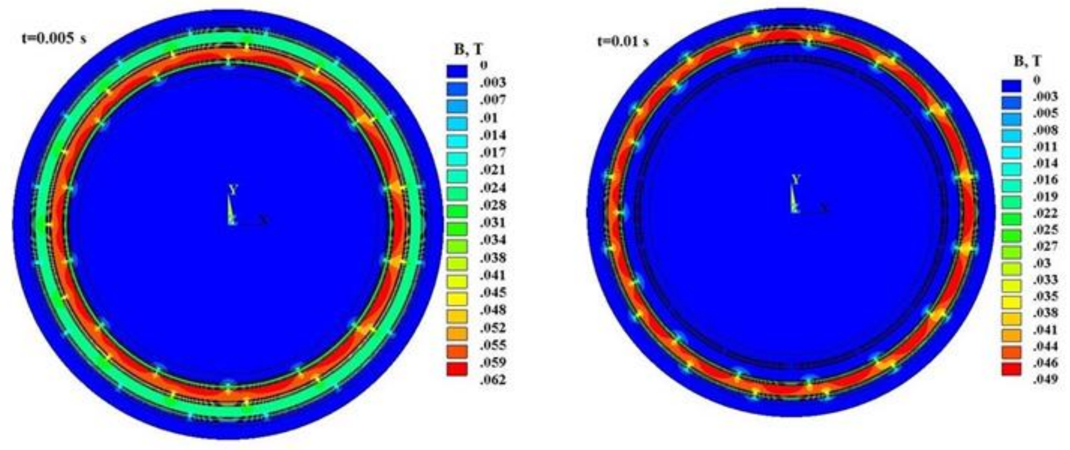
For faster calculations, the simpler 3D FEM model has been developed to simulate spirally wound HTS layers as thin cylinders with anisotropy of electrical conductivity.

10 mesh elements across the HTS layer width of the tapes were used.

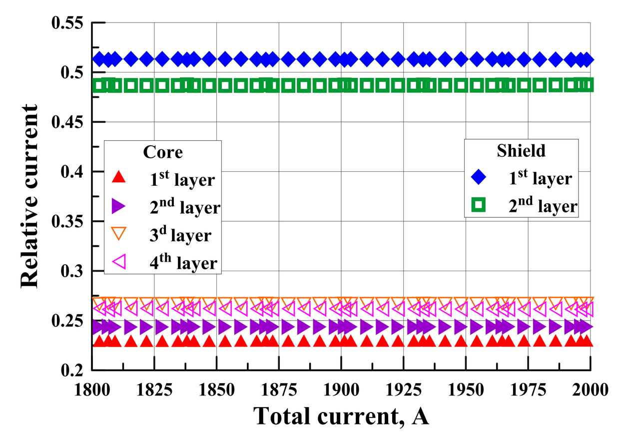
Example of the calculation



Calculated magnetic field distribution at the 2000 A total current in the cable.

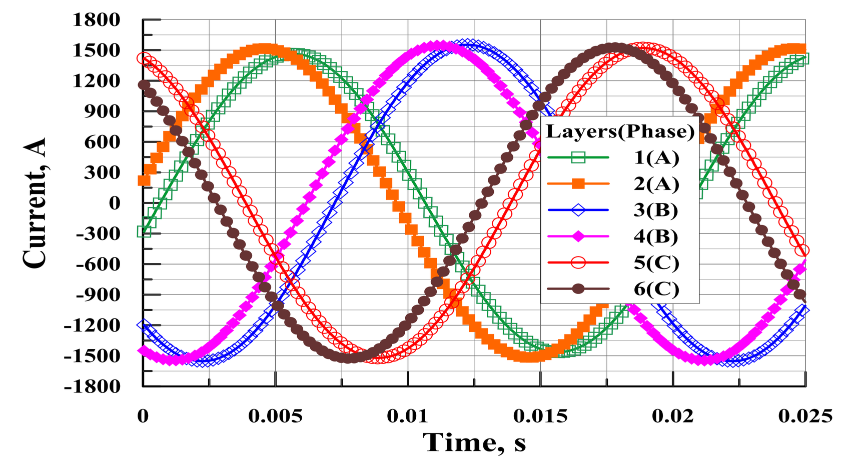


The calculated magnetic fields in the the triaxial cable for two times: left - 0.005 s., right - 0.01 s.



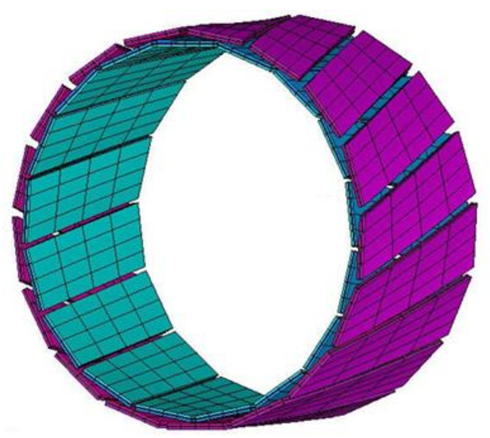
Measured relative current distribution in layers of the cable core and the shield of the HTS cable versus amplitude of the total current.

Result of optimization



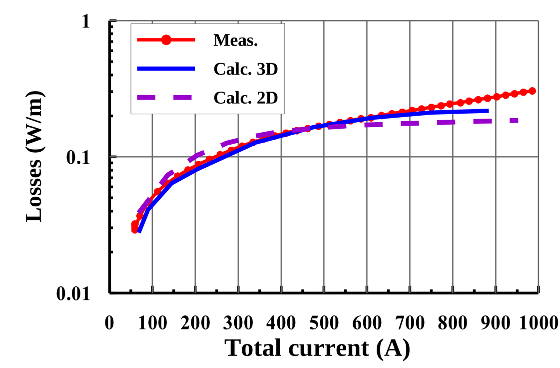
The measured currents in the phases of the triaxial cable at 50Hz frequency.

3D FEM simulation of hysteresis losses in the NiW substrate (only) of 2G HTS tapes of the cable



3D Model

4 mesh elements across the HTS layer width of the tapes were used.



Calculated hysteresis losses in the substrate and measured total losses in the HTS cable versus amplitude of total current at I<0.3 Ic.

Conclusion

The main disadvantage of the licensed software is the long time of calculation of the detailed 3D FEM models. This limitation can be overcome by the use of some open-source software products that usually do not suffer from such shortcomings because of the possibility of changing the mathematical models of the investigated processes and a wide choice of algorithms and methods for generating finite element meshes, analyzing their quality, optimizing for different criteria, and subsequent solving of systems of linear equations.

2D Model for calculating losses in HTS layers of the tapes of the cable

For realization of the possibility to calculate losses in the layer of the 2G HTS tape, the FEM model using ANSYS needs to include the nonlinearity between resistivity (ρ) and current density (J) of the superconductor. This can be realized by iteration algorithm.

$$\rho_i^0, \qquad \rho_i^{k+1} = f(\rho_i^k) = \frac{E_0}{J_{c,i}}\left(\frac{J_i^k}{J_{c,i}}\right)^{n-1} \qquad \frac{\rho_i^{k+1}-\rho_i^k}{\rho_i^k} < \zeta \qquad \rho_i^{k+1} = \rho_i^k + \alpha\cdot\left(\rho_i^{k+1}-\rho_i^k\right)$$

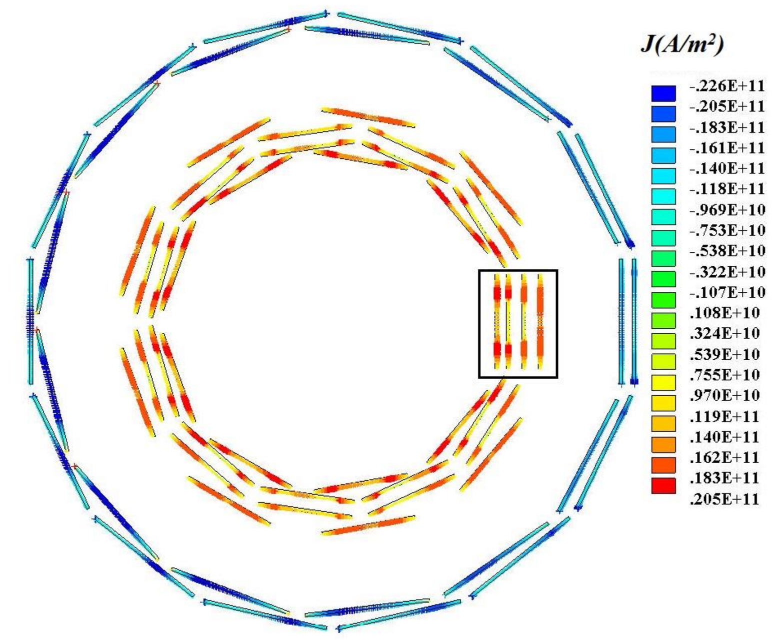
For the correct calculation of the penetration of the magnetic flux in the superconducting material, the HTS layer was meshed with 300 nonuniform quadrilateral-shaped elements across the HTS layer width.

For the correct calculation of the AC losses, it is also important to determine the parameters in an empirical expression that describes the dependence of the critical current density of the 2G HTS tapes from a vector magnetic field and its non-uniformity across the tape width.

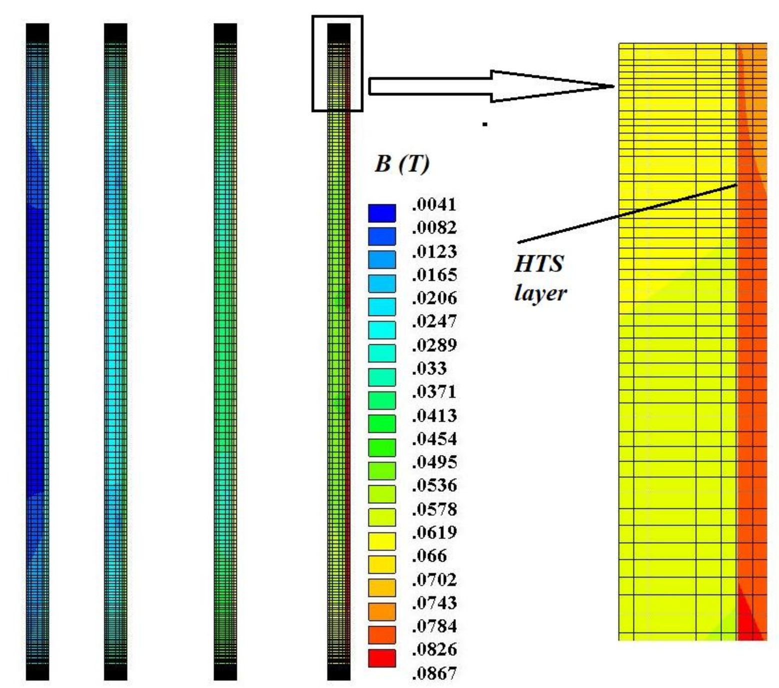
$$J_c\left(\vec{B},x\right) = J_c(B,\theta,x) = J_c(B,\theta)\cdot J_{c0}(x) = \frac{\alpha J_{c0}(x)}{\left(1+\left(k^2\cos^2(\theta)+\sin^2(\theta)\right)^{0.5}\frac{B}{B_0}\right)^{\beta}}$$

$$J_{c0}(x) = J_{c0c}\cdot\begin{cases}1, & if,\ |x|<h_w\cdot w/2\\ \left(1-\frac{2|x|}{w}\right)\frac{1-h_j}{1-h_w}+h_j, & if,\ |x|\geq h_w\cdot w/2\end{cases}$$

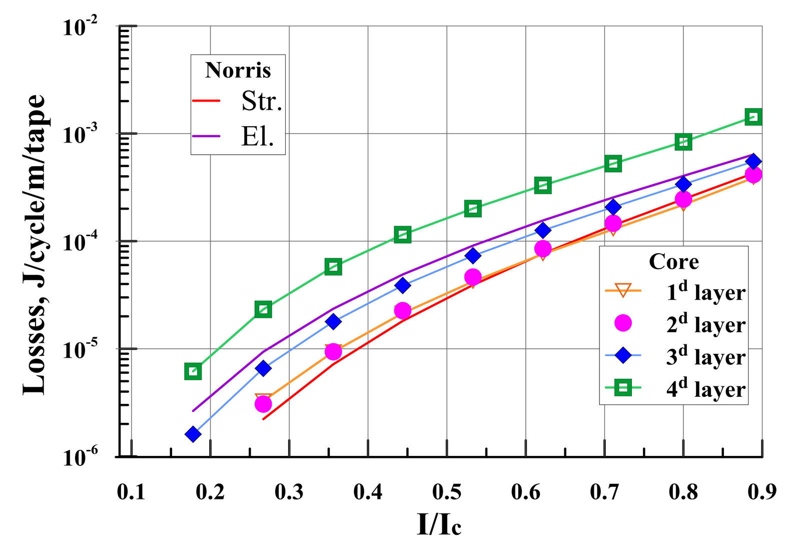
Example of the calculation



The current density distribution in the HTS layers of the cable (4-layer core and the 2-layer shield) .



Dependencies of magnetic field in the tapes of the core .



Calculated losses with Norris model and by FEM model in layers of the core of the cable versus ratio I/Ic.

Topics PS3-AM; Presented at 7th International Workshop on Numerical Modelling of HTS, Nancy, France, June 2021,