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# Magnetic Field and Characteristic Analysis of the Superconducting Fault Current Limiter for DC Applications

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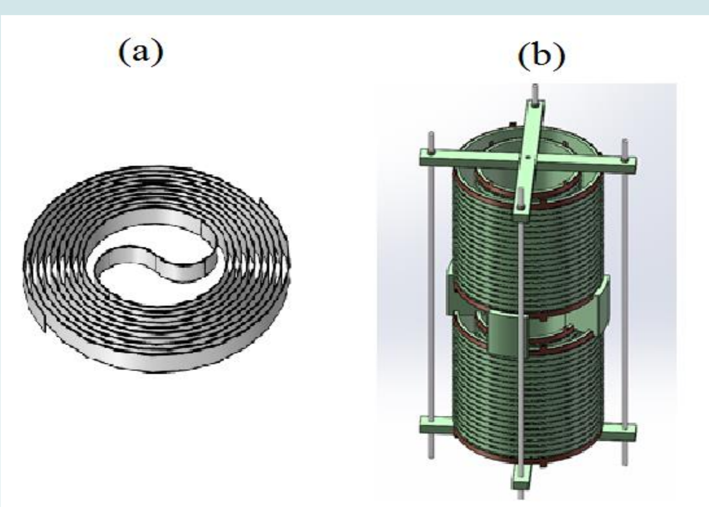
## Abstract

**The DC superconducting fault current limiter is an important component of HVDC power supply protection systems. Because the critical current value of the superconducting tape is associated with the magnetic field around it and the electromagnetic force suffered by the superconducting coil in power supply system faults may damage it, it is necessary for the performance analysis and the optimization design of superconducting fault current limiters to understand the magnetic field distribution and the electromagnetic force.**

**In the paper, the static and the transient magnetic field FEM computational models of DC superconducting fault current limiters for the normal operation and the short-circuit fault are established. Using the static magnetic field model, the magnetic field distribution of a disk and a cylinder superconducting coils is calculated, and using the transient magnetic field model, the transient magnetic field distribution and the electromagnetic force for the two coils are analyzed.**

## Two superconducting coil structures




| Coil configuration | Disc | Cylinder |
|---|---|---|
| Inner radius (mm) | 60 | |
| Outer radius (mm) | 400 | |
| Inside solenoid radius (mm) | | 180 |
| Outside solenoid radius (mm) | | 220 |
| Height (mm) | 12 | 540 |
| Coil turns | 69 | 80 |
| Turn pitch (mm) | 5 | 1.5 |
| Tape length (m) | 100 | 100 |

## Finite element analysis model

### THE DESCRIPTION EQUATION

Static magnetic field

$$\nabla\times\left(\frac{1}{\mu}\nabla\times A_z(x,y)\right)=J_z(x,y)$$

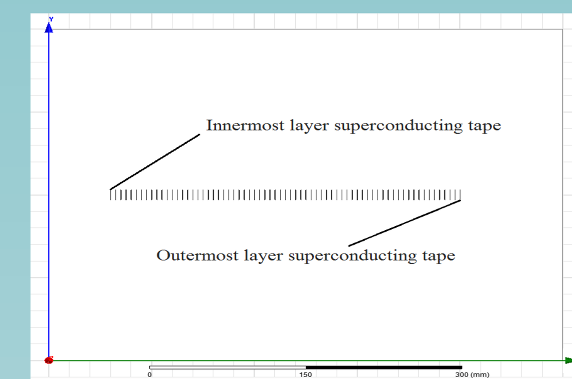
Transient magnetic field

$$\nabla\times\frac{1}{\mu}\nabla\times A=J_s-\sigma\frac{\partial A}{\partial t}$$

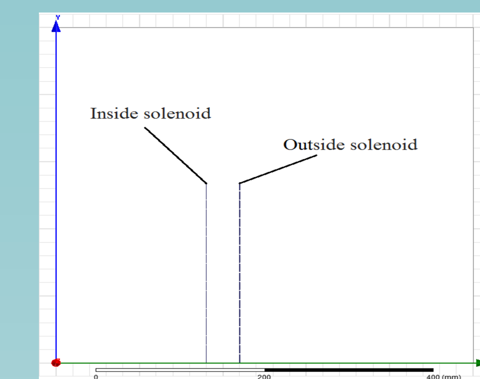
### THE BOUNDARY CONDITIONS

Only the y = 0 boundary edge of the computational domain for the cylinder coil is set as even symmetry boundary condition, the rest is set as the Dirichlet boundary conditions.

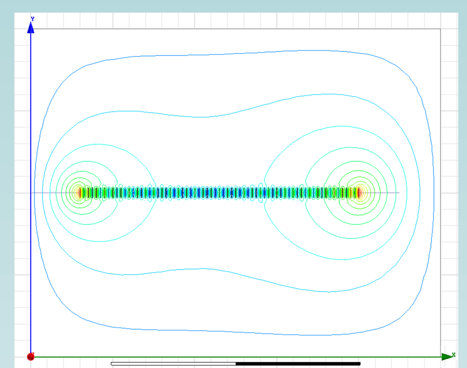
## Static magnetic field analysis



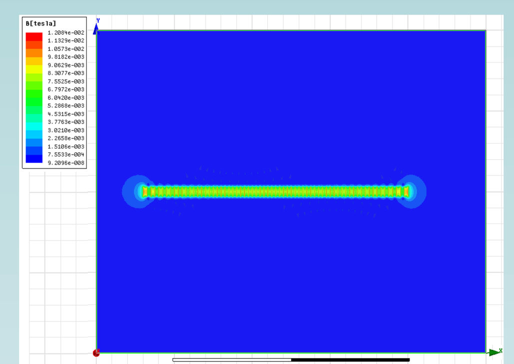

Computational domain of disc coil



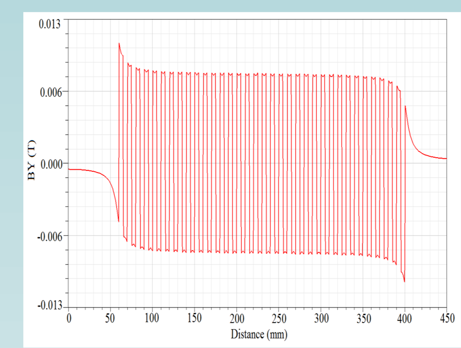

Computational domain of cylinder coil



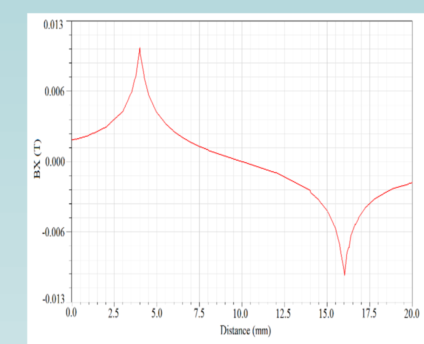
Magnetic field lines



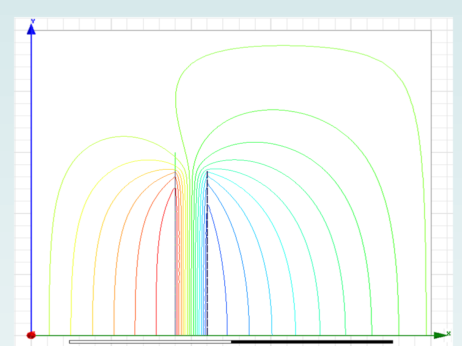
Magnetic flux density



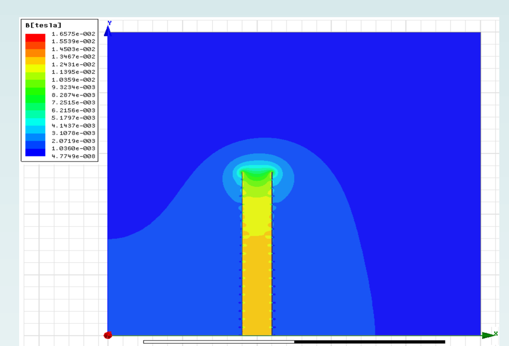
Y component of B



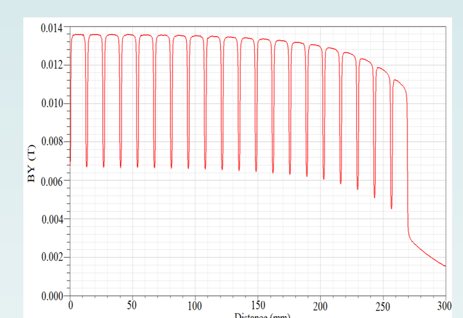
X component of B



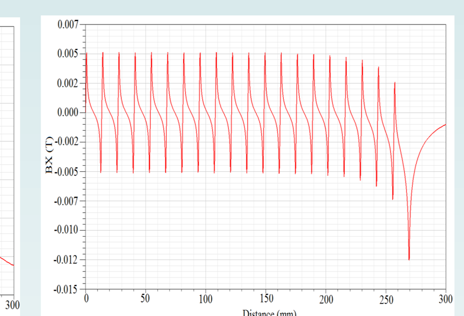
Magnetic field lines



Magnetic flux density



X component of B



X component of B

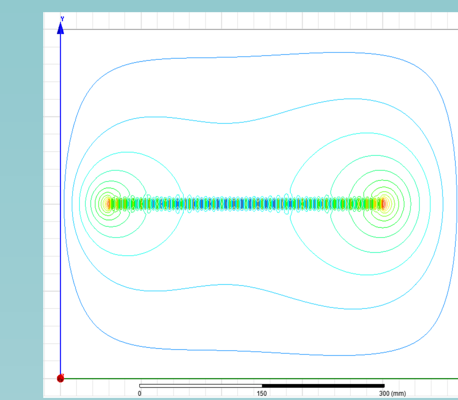
## Transient magnetic field analysis

It is assumed that the normal operating current in the superconducting tape is 150A, a short-circuit fault occurs at time $t$ = 0, the current in the superconducting tape rise from 150A in accordance with the sine law, at $t$ = 3ms it reaches a maximum value of 1500A. That is:

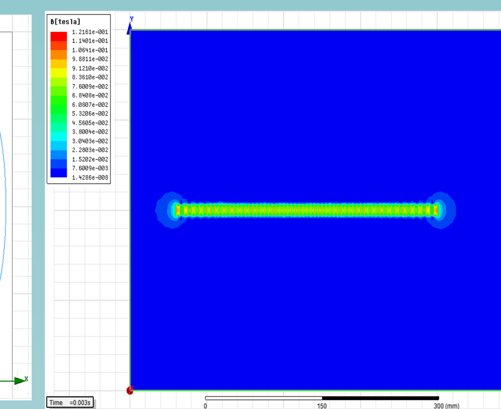
$$I=150+1350\sin(2\pi\times 83.33\times t)$$

where $I$ is the current in the superconducting tape, $t$ is time.

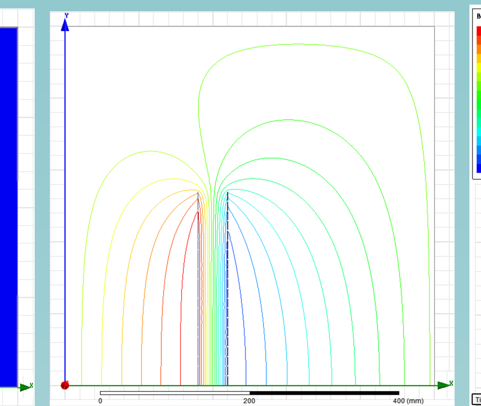
### AT TIME = 3 MS



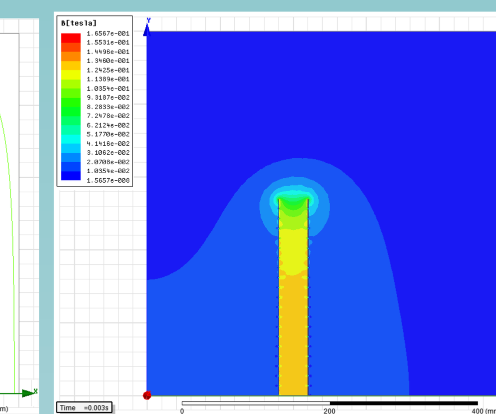
Magnetic field lines



Magnetic flux density



Magnetic field lines



Magnetic flux density

## Comparison of the disc and cylinder coil

### THE MAGNETIC FLUX DENSITY MAXIMUM VALUE

When the current in the superconducting tape is 150A, the magnetic flux density maximum value, and the parallel and perpendicular component maximum value of the magnetic flux density of the cylinder coil is greater than the disc coil. This shows that disc coil has a larger operating current carrying capability.

| | Flux density maximum value | Parallel component | Perpendicular component |
|---|---|---|---|
| **Disc coil** | 120.84GS | 108.33GS | 105.44GS |
| **Cylinder coil** | 165.75GS | 136.10GS | 126.25GS |

### THE RADIAL ELECTROMAGNETIC FORCE

When short-circuit failure, the radial electromagnetic force suffered by the innermost layer superconducting tape of the disc coil is 34.2 N / m at t=3ms, while the radial electromagnetic force suffered by the superconducting tape located in the inside solenoid middle of the cylinder coil is 86.2 N / m. The electromagnetic force suffered by the superconducting tape of disc coil is significantly less than the cylinder coil.

## Conclusion

**The finite element calculation of the two superconducting coils with different structures shows that the disc coil has a larger operating current carrying capability and the electromagnetic force suffered by the superconducting tape of disc coil is significantly less than the cylinder coil.**

**The calculation models and the results in this paper can provide reference for the performance analysis and the optimal design of DC superconducting fault current limiters.**