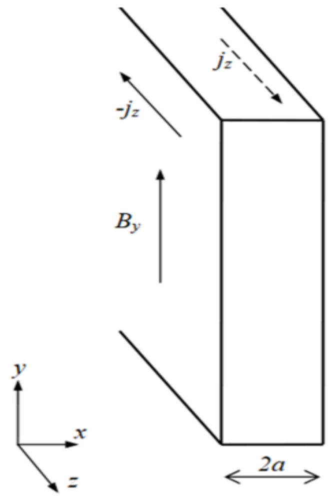
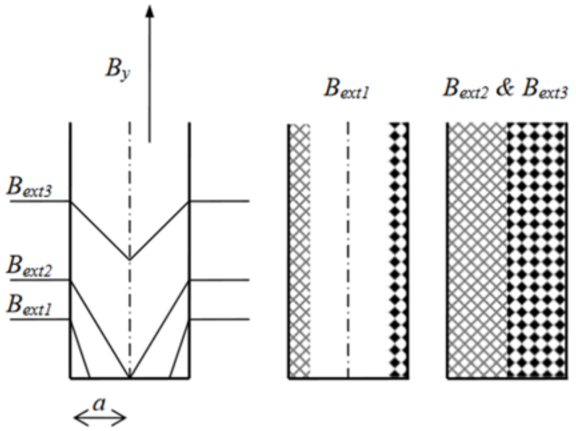
- Since the advent of superconducting magnets, thermomagnetic instabilities have been one of the major issues for scientists. Thermomagnetic instabilities may cause quenches before reaching the critical current of the superconductor.
- Current uneven distribution in the superconductor is the main reason which cause this phenomenon: the current density J is either equal to the critical value J_c or equal zero. The changes of current and magnetic field will then deposit some heat into the superconductor, further decrease J_c, leading to positive feedback and could eventually quench a superconductor magnet far to its expected performance. In the past decades, many theories and stability criteria have been developed to manufacture stable conductors in superconducting science. These theories have analyzed the cause and influencing factors of instability and have been successfully applied to NbTi superconductors. However, for high J_c superconductors, like Nb_3Sn, the inevitable large filament size cannot meet these stability standards in practical applications.
- This study will introduce the main concepts of thermomagnetic instability, deduce the conditions for the occurrence of flux jump based on Bean critical state model and give the simulation results under different conditions.

Theoretical explanation

- In a superconductor under influence of a changing magnetic field, electric currents are induced to flow in such a way as to shield the interior of the superconductor from the changing field. The distribution and the magnitude of these currents are well described by the critical state model. Magnetization of a infinite superconducting slab while ramping up the field By at different times (1,2, and 3) at increasing external field values B_{ext}

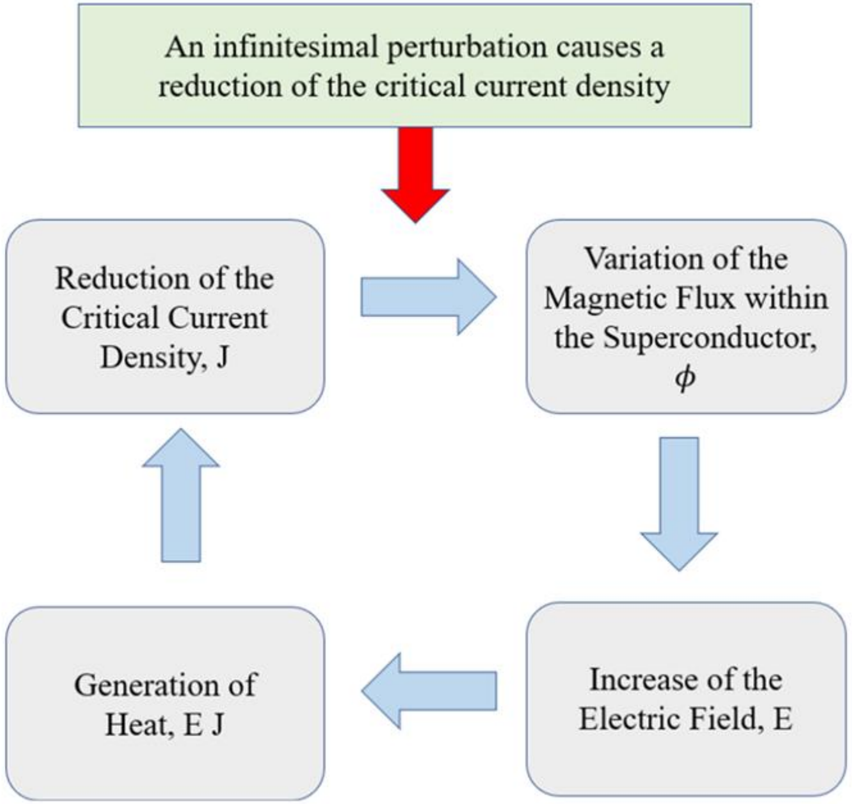
- With the increase of the magnetic field, the screening current currents are induced to flow in the slab. The magnetic field within the slab falls-off from the surface until the field reaches zero, after which the current density becomes zero and the field does not change. By increasing the external field, the region of the density of currents extend further into the slab until they reach the center. There will be no change for the region of currents with further increasing of the field.





Theoretical explanation

- The process of flux jumps is shown in the picture. The external thermal disturbance causes the change of the magnetic flux penetration depth, which in turn causes the change of the magnetic flux passing through the superconductor. The changed magnetic flux induces the electric field and shielding current to produce joule loss. The joule heat causes the temperature of the superconductor to rise, which in turn causes the change of the magnetic flux penetration depth and enters the next cycle. Therefore, it can be found that the magnetic flux jump is a process in which each step promotes each other. Once its initial conditions are met, it will lead to avalanche effect, which makes the temperature of the magnet continuously rise, thus leading to quench.



An infinitesimal perturbation causes a reduction of the critical current density

Reduction of the Critical Current Density, J

Variation of the Magnetic Flux within the Superconductor, ϕ

Increase of the Electric Field, E

Generation of Heat, E J

Numerical analyses

- Equations of magnetocaloric diffusion are given:

$$\nabla \times \left(\rho(\boldsymbol{B},\boldsymbol{J},T)(\nabla \times \boldsymbol{B})\right) + \mu_0 \frac{\partial \boldsymbol{B}}{\partial t} = 0$$

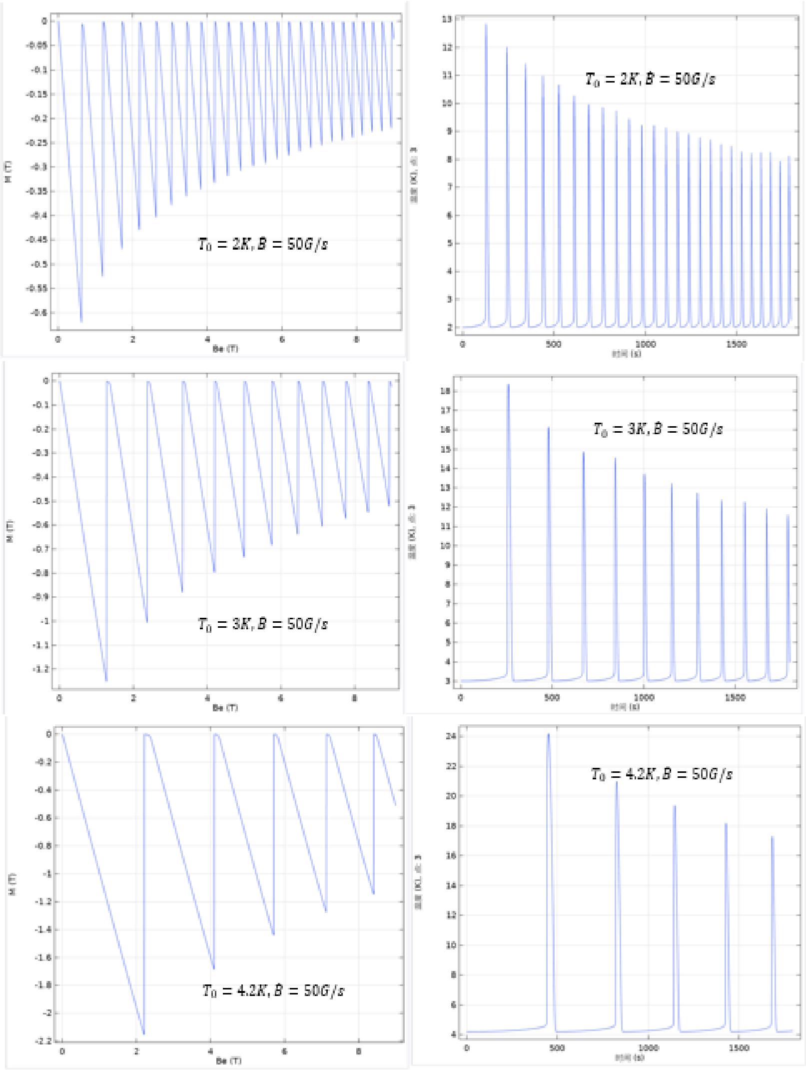
$$\nabla(\lambda \nabla T) - c(T)\frac{\partial T}{\partial t} + W = 0$$

- For 1-D numerical model:

$$c(T)\frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(\kappa \frac{\partial T}{\partial x}\right) + JE, \quad -d < x < d$$

$$\mu_0 \frac{\partial B}{\partial t} = \frac{\partial}{\partial x}\left(\rho(B,T,J)\frac{\partial B}{\partial x}\right), \quad -d < x < d.$$

- The simulation of magnetic curve is shown in the picture. With the increase of coolant temperature, the number of flux jumps and temperature jumps decreases.



Numerical analyses

- With the increase of the sweep rate, the number of flux jumps increases first, but with the further increase of the sweep rate, the number of flux jumps will decrease just as shown in the picture.
- We discussed the influence of the temperature and sweep rate of then field for flux jumps in superconductors. With the increase of the temperature, the number of flux jumps is reduced until there is no flux jump occurs. The numerical predictions are also in good agreement with the measurement data. Next we will analyze other different influencing factors of thermomagnetic instabilities and try to give an optimization scheme for instability.