A Study of Thermomagnetic Instabilities in Type II Superconductors

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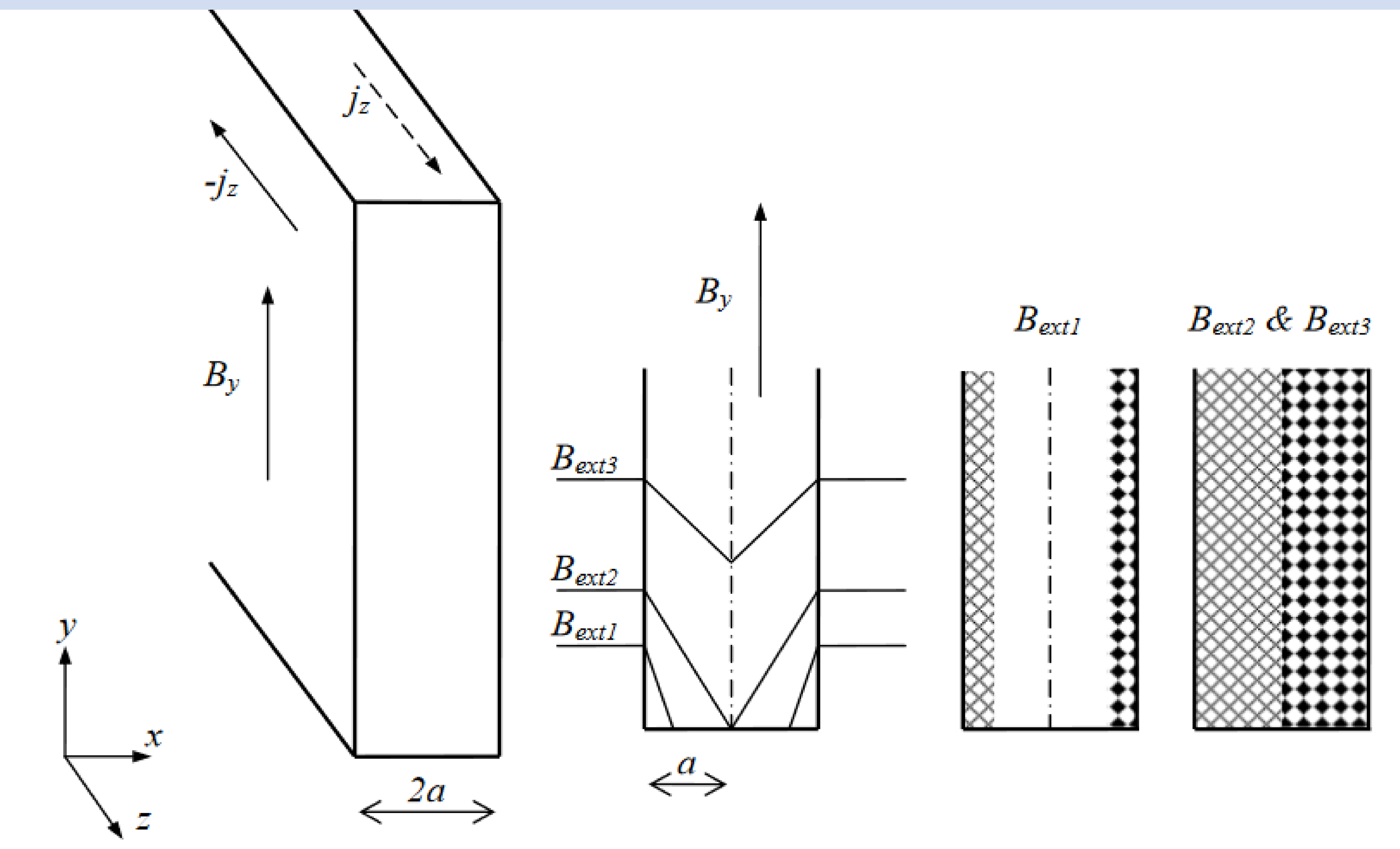
Abstract

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. 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. 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.

A 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.



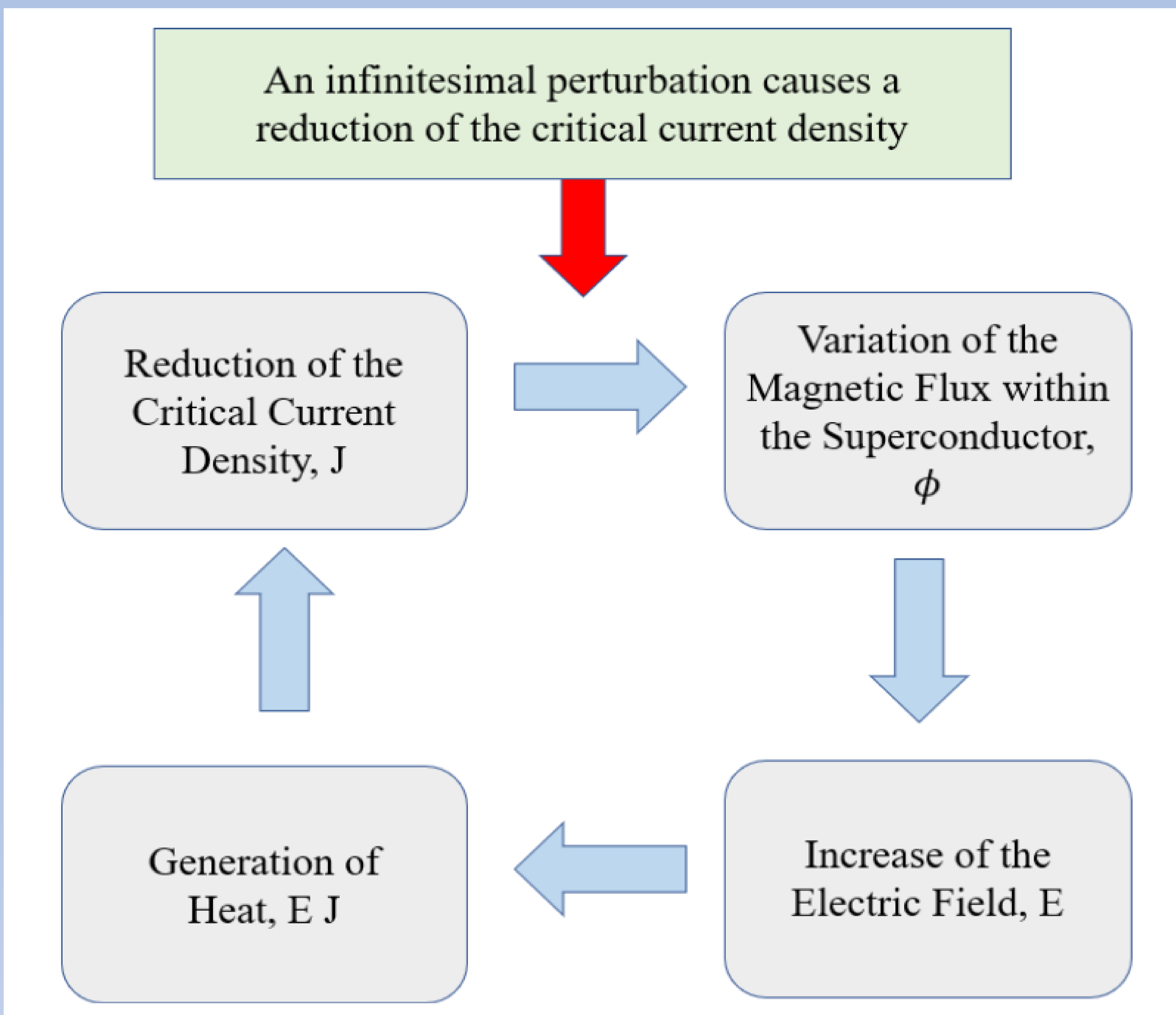
Magnetization of a infinite superconducting slab while ramping up the field By at different times (1,2, and 3) at increasing external field values B_{ext}

Bean has given the field B_{fj} at which a flux jump will first appear:

$$B_{fj} = \mu_0 J_c p_2 = \sqrt{3\mu_0 \gamma c (T_c - T_b)}$$

Then the stability criterion was given:

$$\frac{\mu_0 J_c^2 a^2}{\gamma c (T_c - T_b)} = \beta_s < 3$$



The process of the flux jump

Numerical analyses

Electromagnetic field in superconductor:

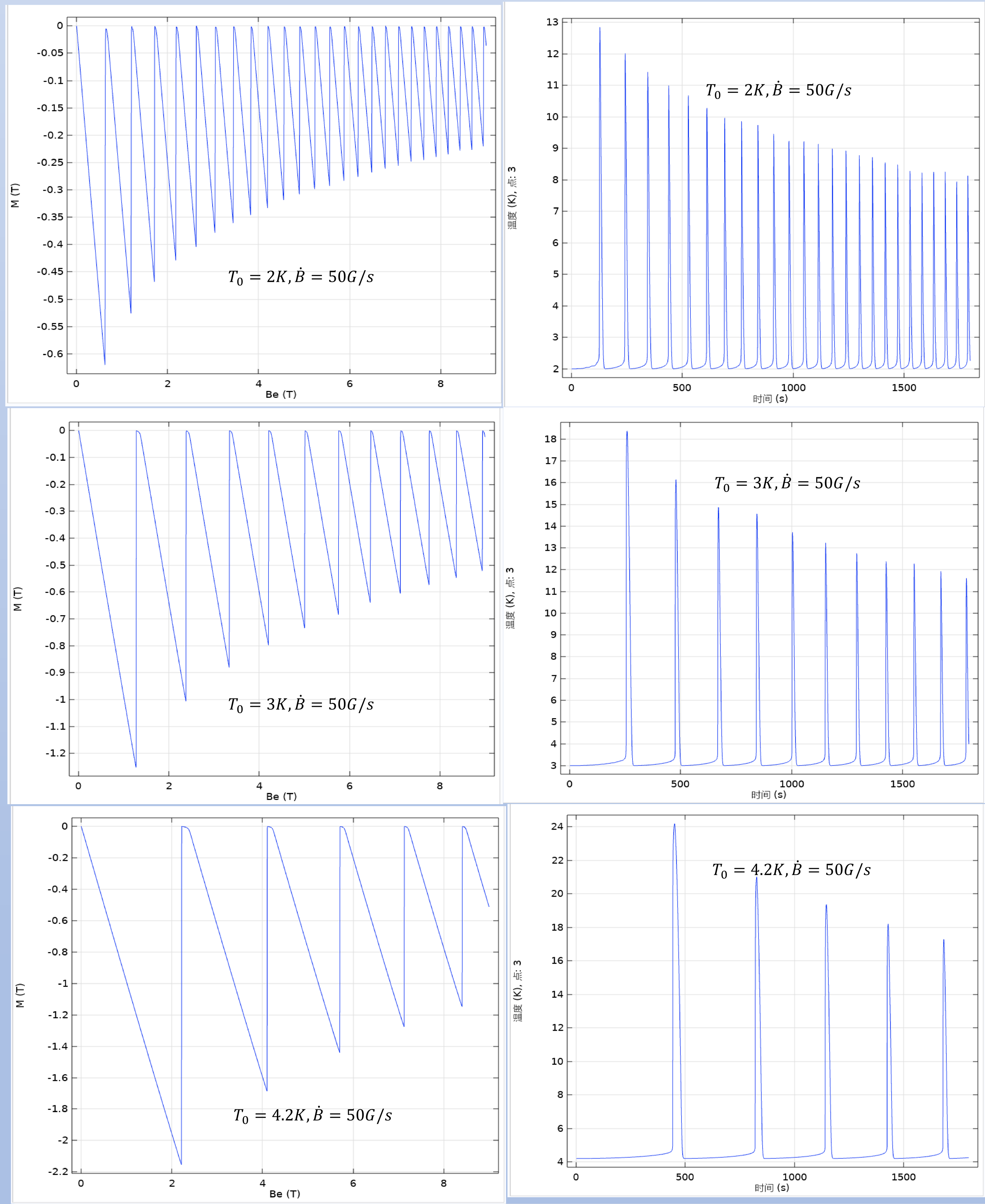
$$\nabla \times \big(\rho(\boldsymbol{B},\boldsymbol{J},T)(\nabla \times \boldsymbol{B})\big) + \mu_0 \frac{\partial \boldsymbol{B}}{\partial t} = 0$$

$$\rho = \left|\frac{B v_0}{J_c}\right| \exp\left(\frac{-U_0}{kT}\right) \exp\left(\frac{J}{J_m}\right)$$

Heat conduction in superconductor:

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

Results of simulation



The simulated magnetization curve under different coolant temperature when the sweep rate is 50 G/s.

Conclusion

Here we discussed the influence of the temperature 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. Next we will analyze other different influencing factors of thermomagnetic instabilities and try to give an optimization scheme for instability.