AC Loss of a Quasi-isotropic Strand Stacked by 2G Wires by Numerical Simulation in Cryogenic Temperature

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Background

Due to high current carrying capacity and well mechanical property at low temperatures and large background magnetic fields, quasi-isotropic strands fabricated by 2G high temperature superconducting (HTS) wires show great potential for applications such as large-scale superconducting magnets or fusion reactors at low temperatures. During the charge of superconducting magnets, quasi-isotropic strands of magnets in use will inevitably produce AC loss. The generated AC loss will results in heating of the strand and may cause the magnets quench. In order to design and protect the magnets, it is necessary to precisely study ac loss properties of quasi-isotropic strands at low temperatures and low frequency magnetic fields.

Objectives

- Ac loss numerical study of quasi-isotropic strand fabricated by second generation (2G) wires in cryogenic temperatures of 4.2 K and 77 K.
- Field amplitude dependence and field frequency dependence of ac losses of quasi-isotropic strand
- Effects of Cu sheath and field angle with strand on ac loss characteristics of quasi-isotropic strand

Model Description

Model Geometry

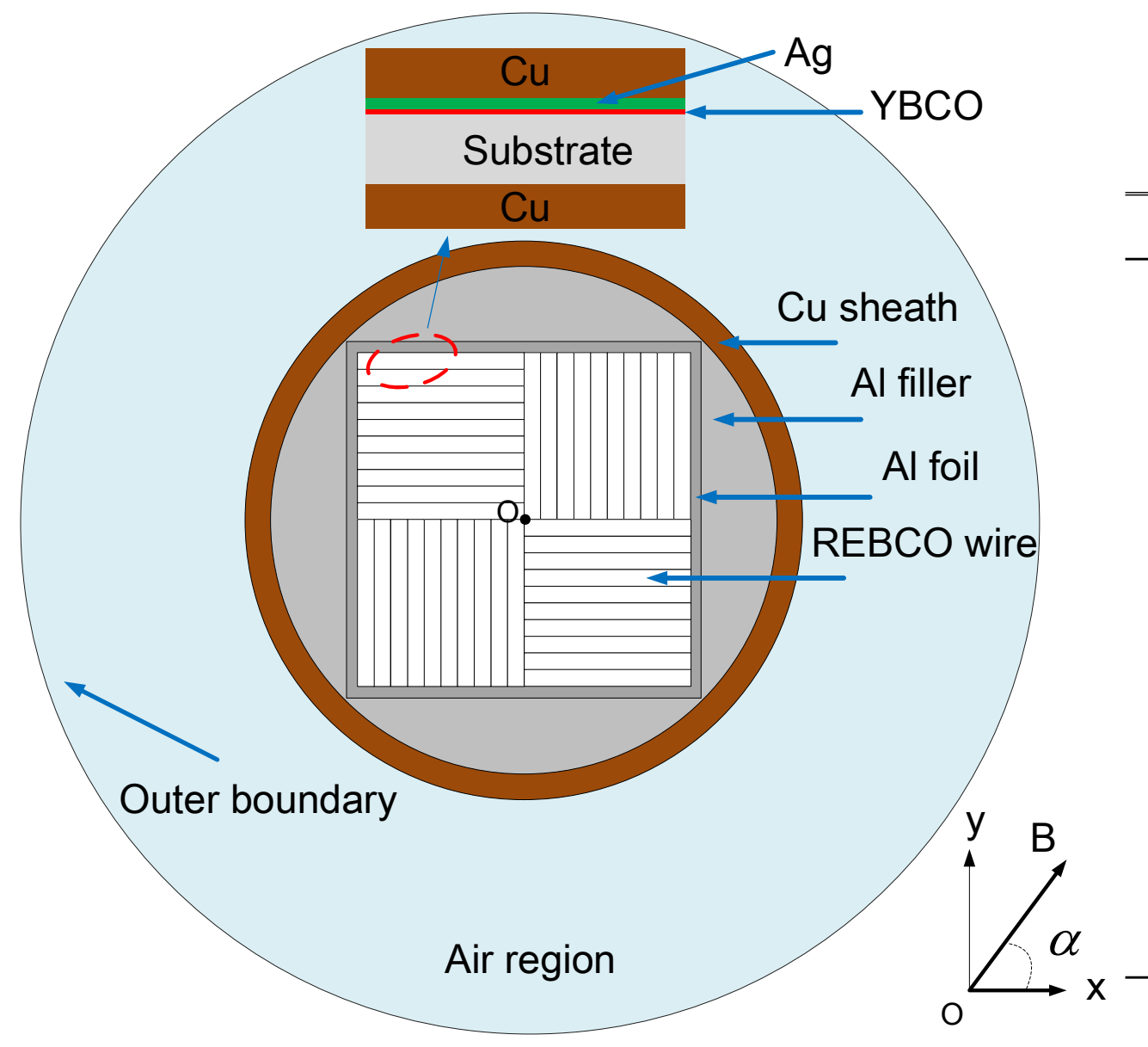


Table I
Main parameters of the wire and strand

Parameter	Value
Thickness of REBCO wire	0.1 mm
Width of REBCO wire	2 mm
Critical current (4.2 K, sf)	558 A
Thickness of aluminum foil	0.1 mm
Inner diameter of copper sheath	7 mm
Outer diameter of copper sheath	8 mm
Number of wires	72
Cu layer thickness	20 um
Sub layer thickness	50 um
Ag layer thickness	2 um
YBCO layer thickness	1 um

Fig. 1. Geometry of quasi-isotropic strand model (not to scale).External magnetic field is imposed on the strand with angle α.

Model Equations

The numerical study is based on the *H*-formulation of Maxwell's equations solved by the finite element method (FEM).

$$\begin{cases} \dfrac{\partial E_z}{\partial y} = -u_0 u_r \dfrac{\partial H_x}{\partial t} \\ \dfrac{\partial E_z}{\partial x} = u_0 u_r \dfrac{\partial H_y}{\partial t} \end{cases} \qquad J_z = \frac{\partial H_y}{\partial x} - \frac{\partial H_x}{\partial y}$$

$$E_z = \rho \cdot J_z$$

$$\rho(J) = \frac{E_c}{J_c(B,\theta)} \left| \frac{J_z}{J_c(B,\theta)} \right|^{n-1}$$

Table II
Resistivity of normal metal at 4.2 K and 77 K temperatures

Parameter	4.2 K	77 K
air resistivity	1 Ω/m	1 Ω/m
Ag resistivity	0.0128 nΩ/m	2.70 nΩ/m
Cu resistivity	0.16 nΩ/m	1.97 nΩ/m
Sub resistivity	1.23 uΩ/m	1.25 uΩ/m
Al resistivity	0.82 nΩ/m	3.1 nΩ/m

Boundary conditions

Time-varying external magnetic field $B_0\sin(\omega t)$ is imposed on the outer boundary of the model with field angle α .

$$\begin{cases} B_x = B_0 \sin(\omega t) \cdot \cos\alpha \\ B_y = B_0 \sin(\omega t) \cdot \sin\alpha \end{cases}$$

Average ac loss ($J \cdot m^{-1} \cdot$ ycle^{-1}) of quasi-isotropic strand can be calculated by means of the formula .

$$Q = 2\int_{T/2}^{T} dt \int_{\Omega} E \cdot J dxdy$$

Hysteresis loss(Q_h) can be distinguished from eddy current loss (Q_e)and coupling loss (Q_p) by calculating the power separately for the superconducting elements and for the normal conducting elements, respectively.

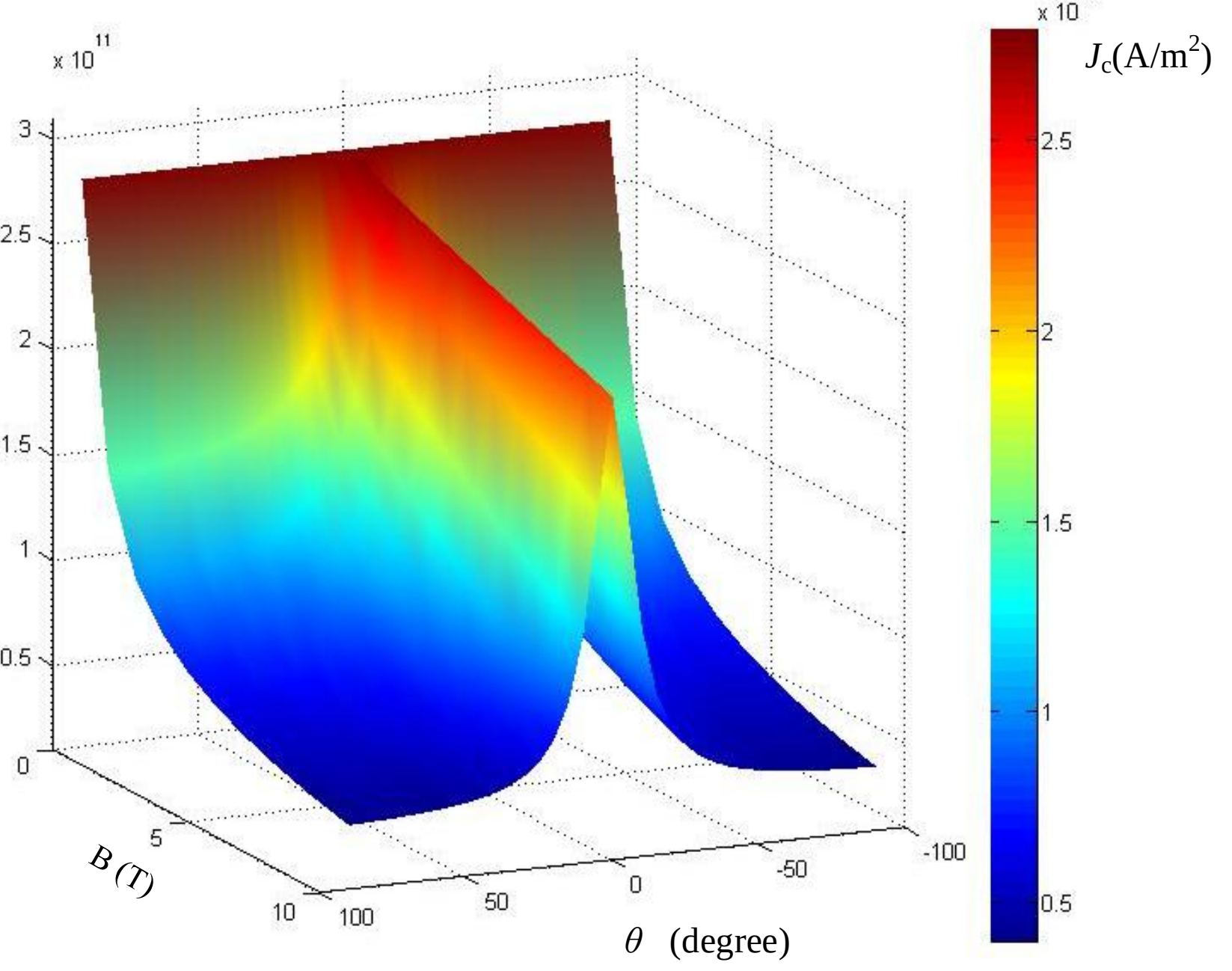
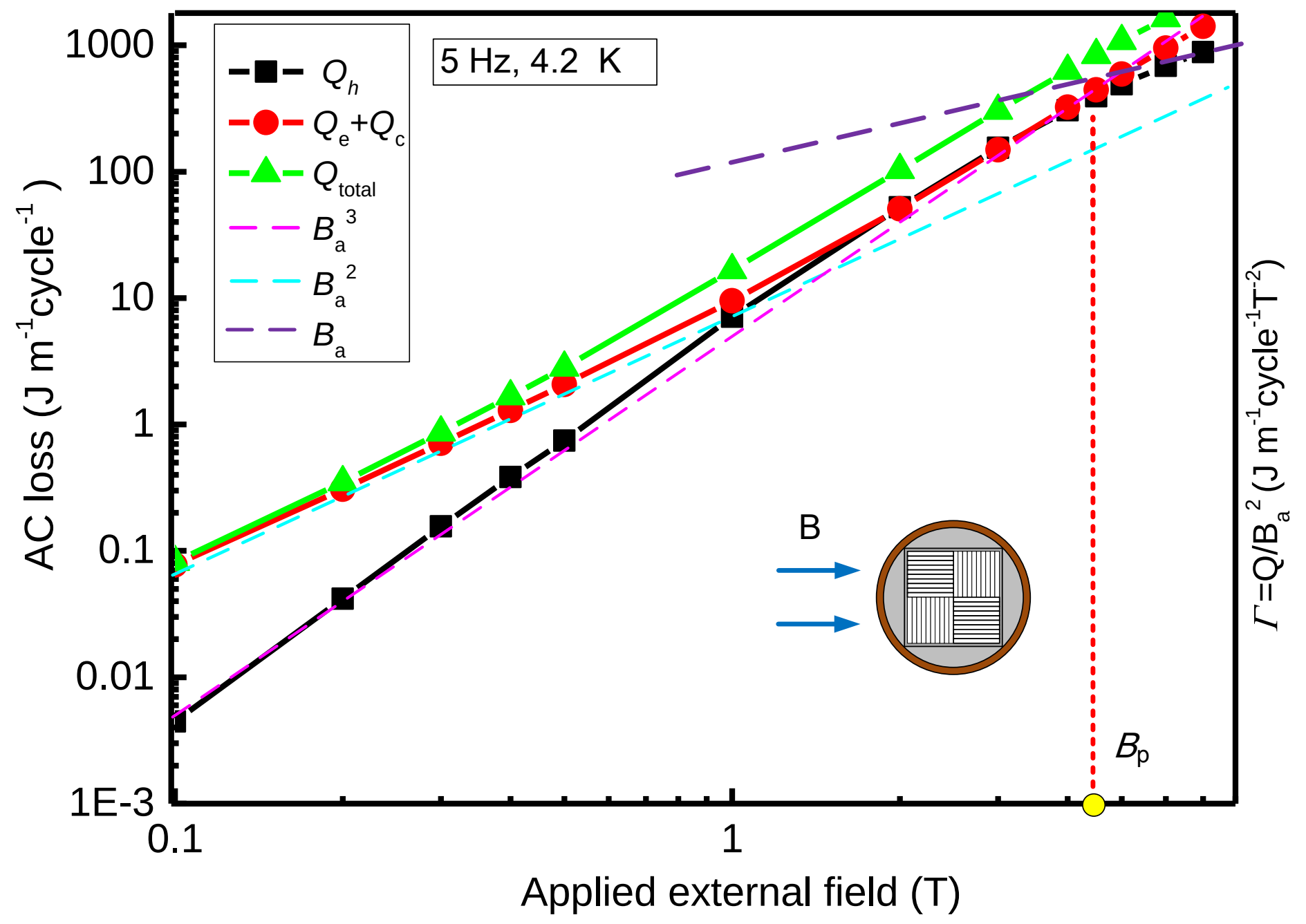
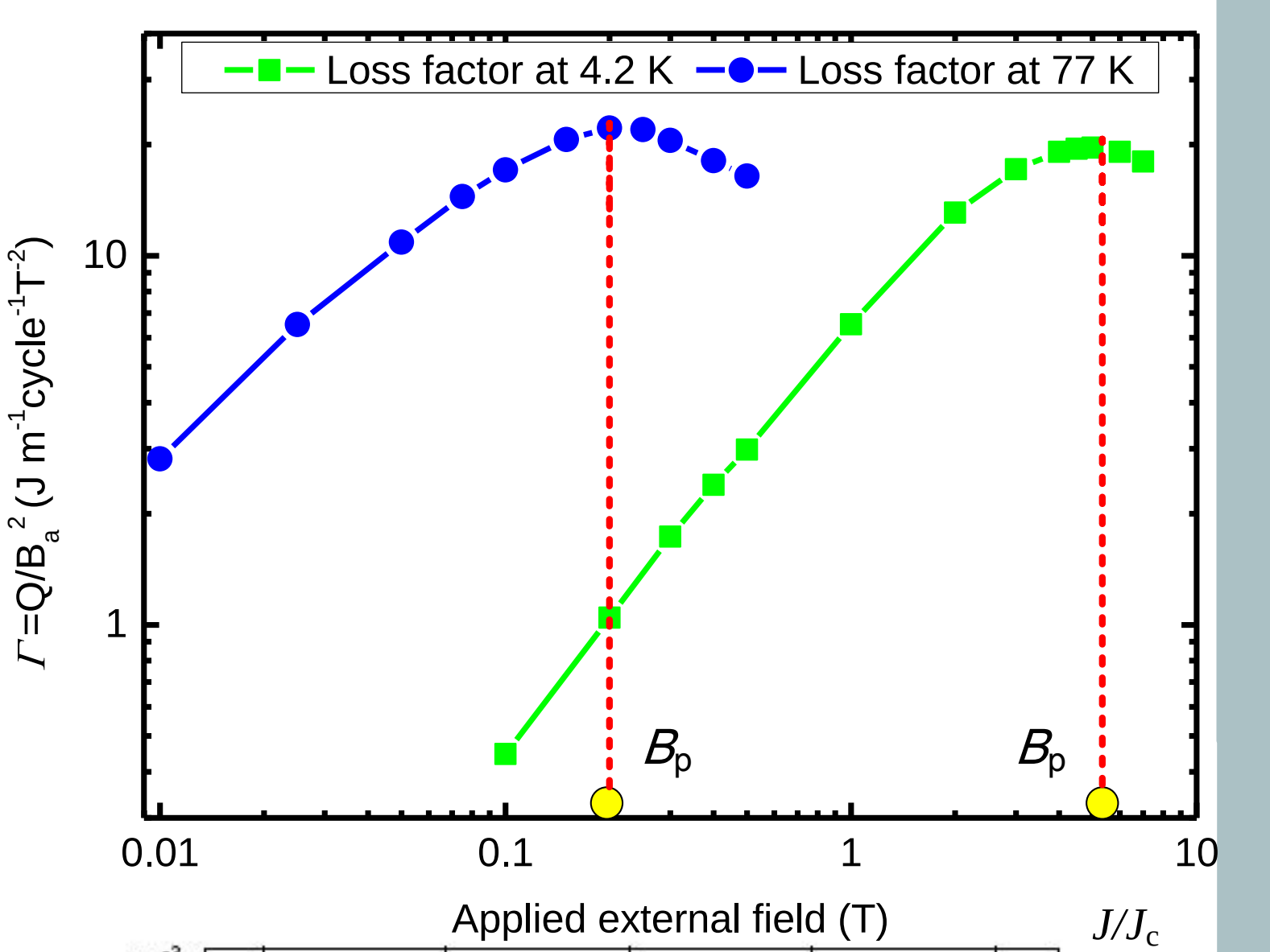


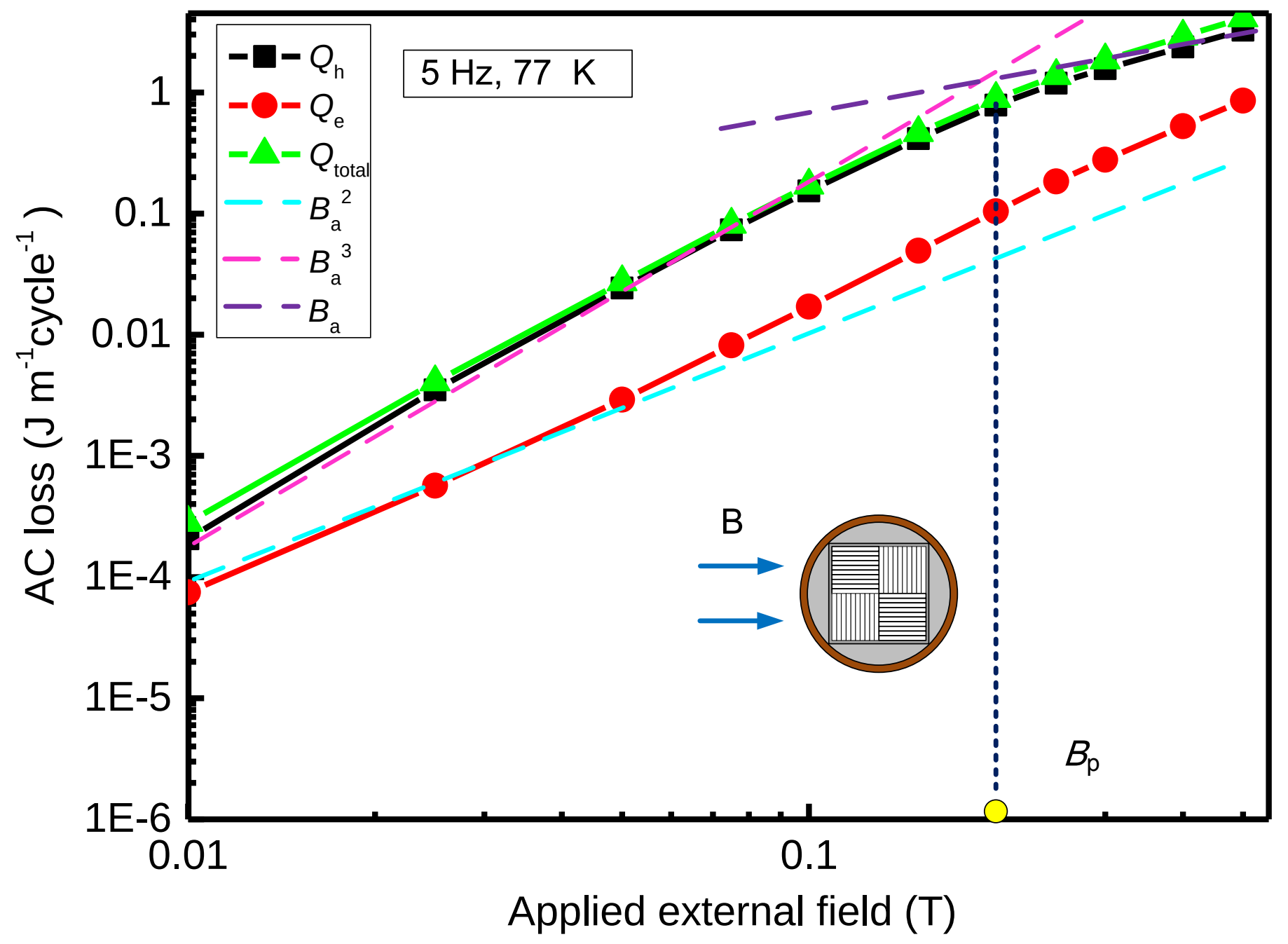
Fig. 2 Critical current as a function of magnetic field and field angle of REBCO coated conductor at 4.2 K temperature.

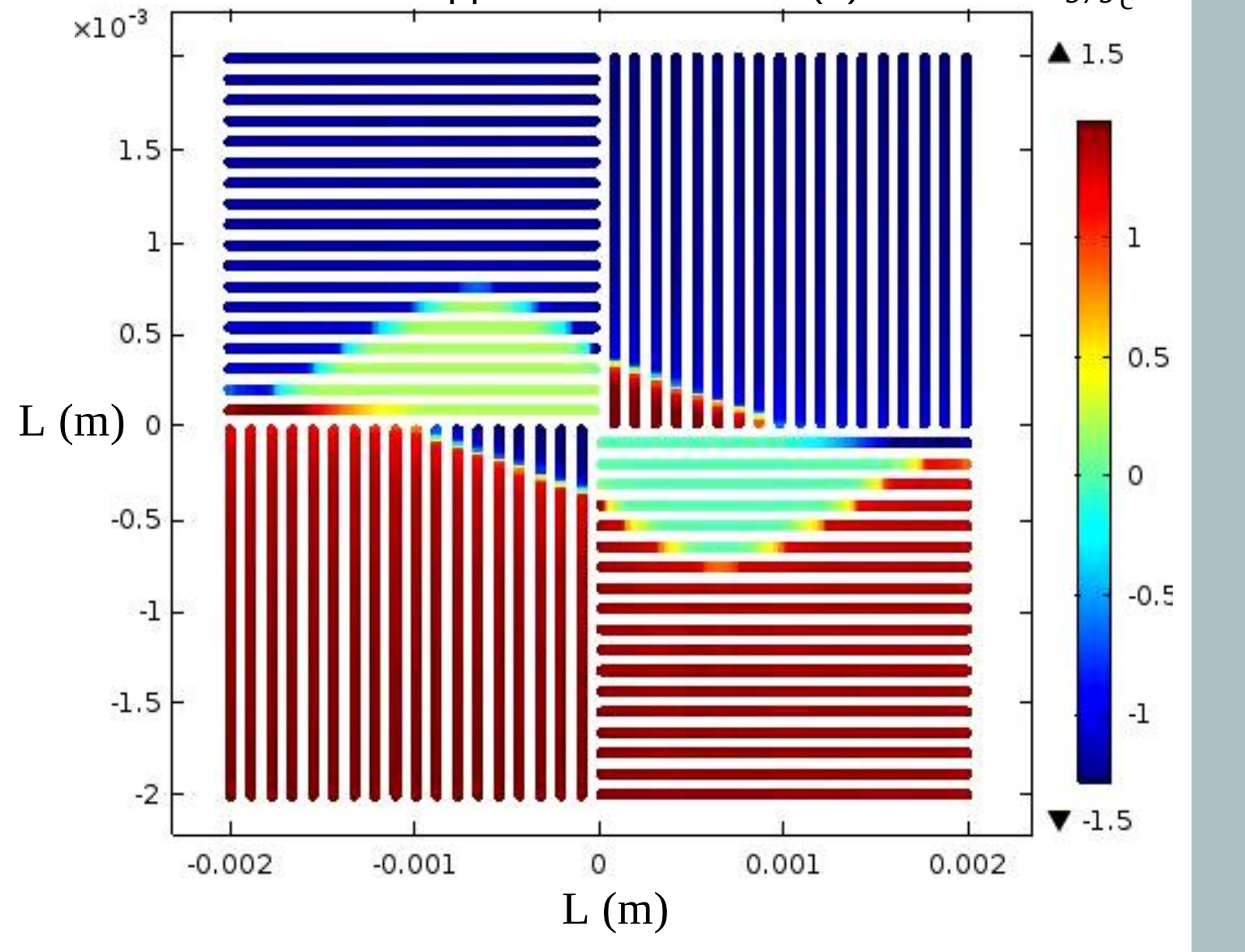
Results

Field amplitude dependence of ac loss of the strand





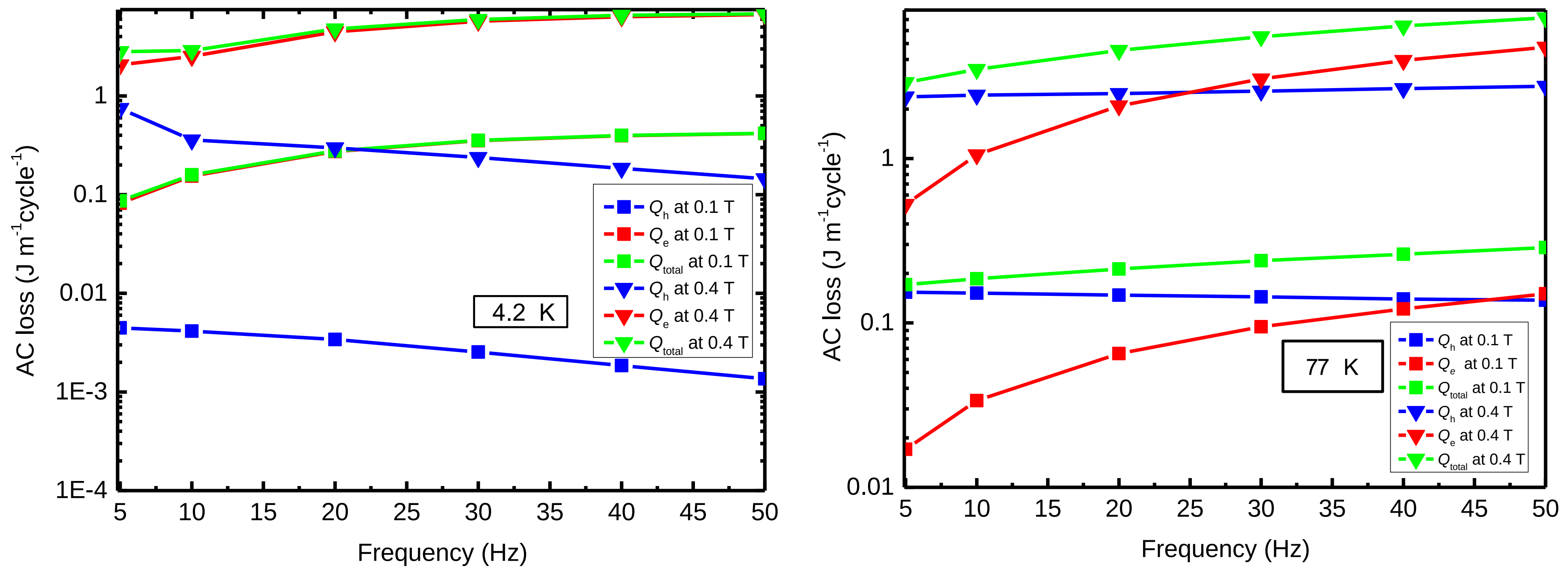




Normalized current density distribution for quasi-isotropic strand at the penetration field 4.5 T and temperature of 4.2 K.

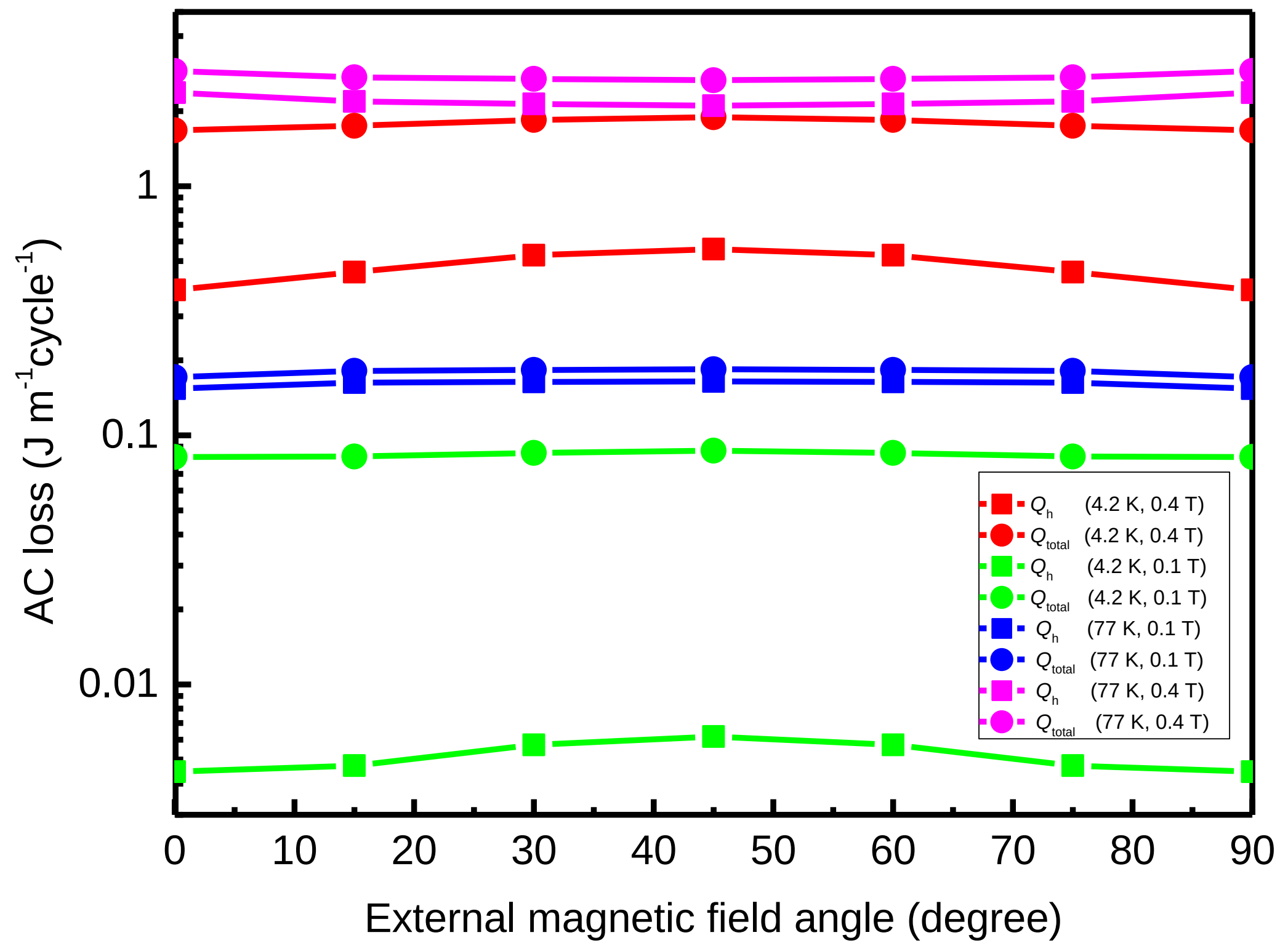
Results

Frequency dependence of ac loss of quasi-isotropic strand



At low fields and 4.2 K , sum of eddy current loss and coupling loss is the dominant loss and is an order of magnitude larger than the hysteresis loss, which is different from the case of 77 K. Among the loss, most parts are contributed by the Cu sheath. Eddy current loss and coupling loss of the strand increases with a linear dependence on *f.* While hysteresis loss in the strand has a decreasing frequency dependence, when the applied magnetic fields are lower than the penetration fields in both temperatures.

Angular dependence of ac loss of the strand



For quasi-isotropic strand has a symmetry geometry structure, the magnetic field angle imposed is merely varied to the 90 degree.

Conclusions

- ➢ The penetrated fields of quasi-isotropic strand at 4.2 K and 77 K are 4.5 T and 0.2 T respectively, determined by loss factor versus magnetic field amplitudes. Loss factorΓ has a constant peak value, Γmax ～ 20, at temperatures of 4.2 K and 77 K.
- ➢ As the resistivity decreases in 4.2 K, the eddy current loss and coupling loss of quasi-isotropic strandimmensely increases , which is not obviously in the 77 K case.
- ➢ Hysteresis loss in the strand has a decreasing frequency dependence, when the applied magnetic fields are lower than the penetration fields at both 4.2 K and 77 K temperatures.
- ➢ At 4.2 K temperature, 0.1 T and 0.4 T magnetic fields, total ac loss and hysteresis loss along field angles are both symmetric at 45 degree field angle with a maximum value. However, when the magnetic field at 77 K increases to 0.4 T, the trends of total ac losses and hysteresis losses became the inverse with a minimum value at 45 degree field angle.

➢Next, ac losses of sample strands in 4.2 K and 77 K temperatures will be tested to verify the simulated results.

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