Determination of the Field Dependence of the Surface Resistance of Superconductors from Cavity Tests (TUPO035)

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Introduction

- The goal of our program is to get a better understanding of the physics of the mechanisms limiting the performance of superconductors in the frequency range of interest for accelerators
- The research consists of experimental and theoretical parts to address the unresolved issues of the surface resistance of superconductors at high rf field, and in particular how the surface composition and structure can be modified and tuned in order to reduce surface resistance.
- One of the most effective ways to understand a physical process is to analyze its frequency dependence
- How can we extract the “real” field dependence of the surface resistance from cavity tests?

Extracting Real $R_s(H)$ from $Q(H_p)$

- Geometrical factor

$$G = \frac{\omega \int \mu_0 |\mathbf{H}|^2 \, \mathrm{d}v}{\int |\mathbf{H}|^2 \, \mathrm{d}a}$$

$G = QR_s$ only if R_s (or Q) is constant

- Average surface resistance $\overline{R_s}(H_p) = G / Q(H_p)$

$$\overline{R_s}(H_p) \int_S |\mathbf{H}(r)|^2 \, \mathrm{d}S = \int_S R_s[H(r)] |\mathbf{H}(r)|^2 \, \mathrm{d}S$$

- Define $a(h)$ as the fraction of the total cavity area where $|H| \le h H_p$
  - Continuous, monotonically increasing $\left.\frac{\mathrm{d}a}{\mathrm{d}h}\right|_{a=1} = \infty$
  - $a(0) = 0 \qquad a(1) = 1$

$$\overline{R_s}(H) \int_0^1 (hH)^2 \frac{\mathrm{d}a}{\mathrm{d}h} \mathrm{d}h = \int_0^1 R_s(hH)(hH)^2 \frac{\mathrm{d}a}{\mathrm{d}h} \mathrm{d}h$$

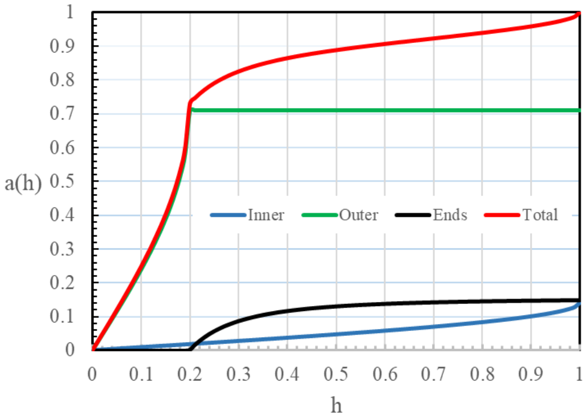
Extracting Real $R_s(H)$ from $Q(H_p)$

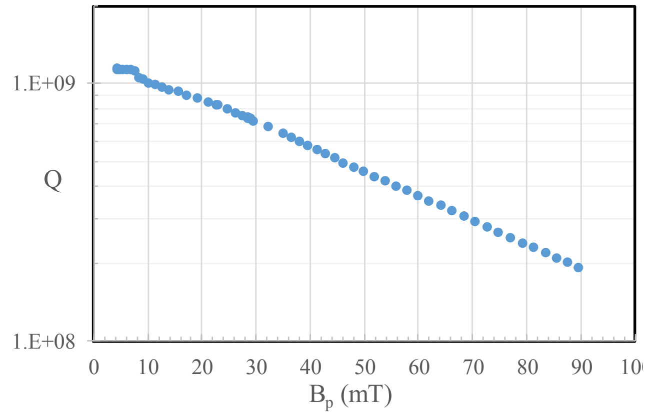
- Model $\overline{R_s}(H)$ by $\overline{R_s}\left(\frac{H}{H_0}\right) = \overline{R_0}\sum_{\alpha_i} r_{\alpha_i}\left(\frac{H}{H_0}\right)^{\alpha_i}$
  - H_0 arbitrary, to make coefficients dimensionless
  - α_i : suite of non-negative real numbers
- Assume $R_s\left(\frac{H}{H_0}\right) = R_0\sum_{\alpha_i} \beta(\alpha_i)\, r_{\alpha_i}\left(\frac{H}{H_0}\right)^{\alpha_i}$

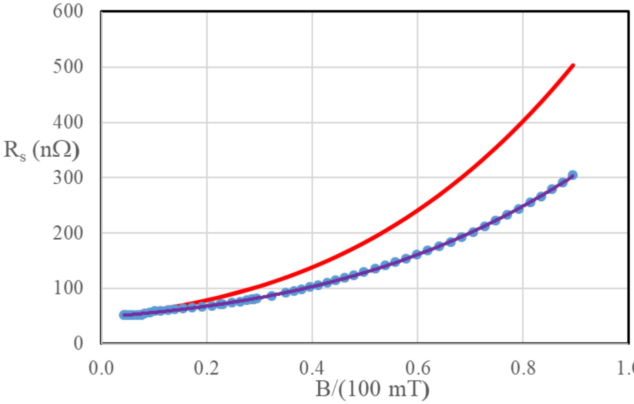
$$\beta(\alpha_i) = \frac{\int_0^1 h^2 \frac{\mathrm{d}a}{\mathrm{d}h}\mathrm{d}h}{\int_0^1 h^{2+\alpha_i}\frac{\mathrm{d}a}{\mathrm{d}h}\mathrm{d}h} = \frac{2\int_0^1 h\left[1-a(h)\right]\mathrm{d}h}{(2+\alpha_i)\int_0^1 h^{1+\alpha_i}\left[1-a(h)\right]\mathrm{d}h}$$

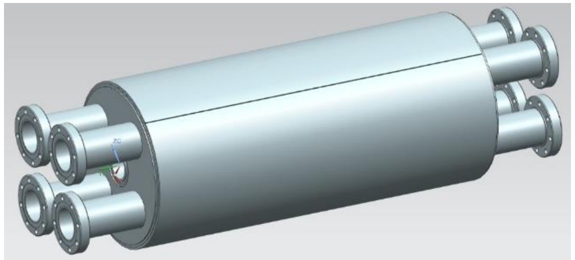
  - Continuous, monotonically increasing $\beta(0)=1, \quad \beta(\alpha_i) > \beta(\alpha_j) \text{ if } \alpha_i > \alpha_j$
  - $[1\text{-}a(h)]$ is the fraction of the total cavity area where $|H| > h\,H_p$

Field Dependence of Surface Resistance









$$B_0 = 100 \text{ mT}$$

$$\overline{R}_s\left(\frac{B}{B_0}\right) = 48.2\left[1 + 1.54\left(\frac{B}{B_0}\right) + 2.03\left(\frac{B}{B_0}\right)^2 + 3.20\left(\frac{B}{B_0}\right)^3\right]$$

$$\beta_0 = 1, \quad \beta_1 = 1.46, \quad \beta_2 = 1.79, \quad \beta_3 = 2.04$$

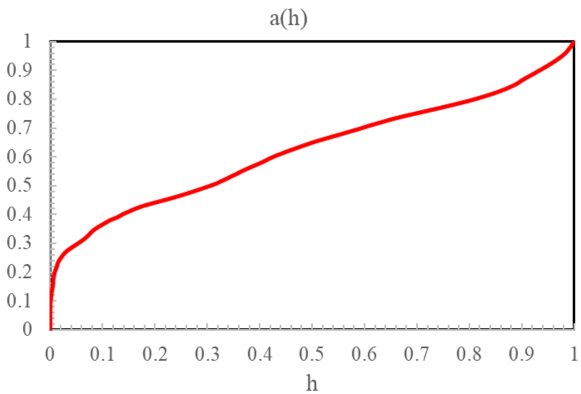
$$R_s\left(\frac{B}{B_0}\right) = 48.2\left[1 + 2.24\left(\frac{B}{B_0}\right) + 3.63\left(\frac{B}{B_0}\right)^2 + 6.52\left(\frac{B}{B_0}\right)^3\right]$$

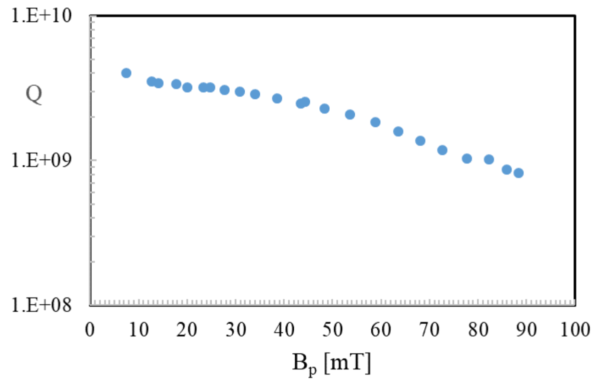
325 MHz

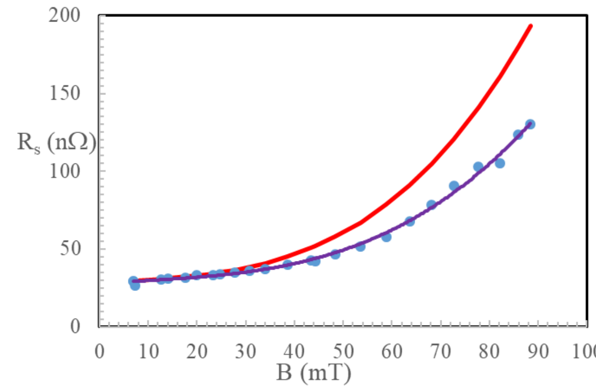
4.3 K

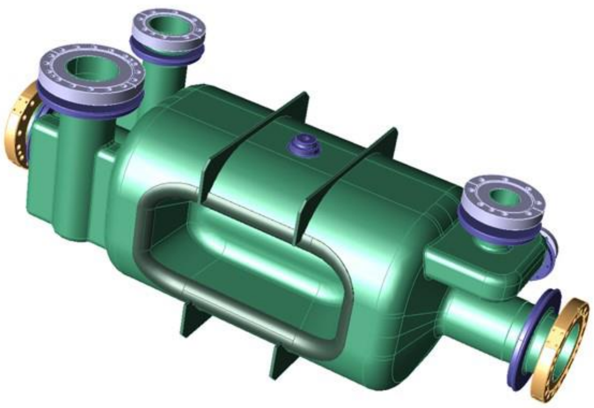
G=59 Ω

Field Dependence of Surface Resistance









400 MHz

4.3 K

G=107 Ω

$$B_0 = 100 \text{ mT}$$

$$\overline{R}_s\left(\frac{B}{B_0}\right) = 27.8\left[1 + 0.77\left(\frac{B}{B_0}\right) - 1.44\left(\frac{B}{B_0}\right)^2 + 6.00\left(\frac{B}{B_0}\right)^3\right]$$

$$\beta_0 = 1, \quad \beta_1 = 1.24, \quad \beta_2 = 1.44, \quad \beta_3 = 1.63$$

$$R_s\left(\frac{B}{B_0}\right) = 27.8\left[1 + 0.95\left(\frac{B}{B_0}\right) - 2.07\left(\frac{B}{B_0}\right)^2 + 9.76\left(\frac{B}{B_0}\right)^3\right]$$

More details at TUPO035