Investigation of AC loss in filamentized coated conductor tapes 4 mm and 12 mm wide, with the filaments of 500 μm and 250 μm, prepared by industrial process

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Initial remarks

REBCO deposited by low-cost industrial 2LUPS process utilizing the 3D filamentized metal tape as substrate

A Wulff et al., Supercond. Sci. Technol. 28 (2015) 072001
A R Insinga et al., IEEE Trans. Appl. Supercond.. 28 (2018) 6601705
A R Insinga et al., IEEE Trans. Appl. Supercond.. 29 (2019) 8200704

standard

striation
(mechanical, chemical,…

Ag, Cu
REBCO
buffer(s)
substrate

patterned substrate

Samples prepared within Eurostars-2 project “Filaments4Fusion”

eurostars™

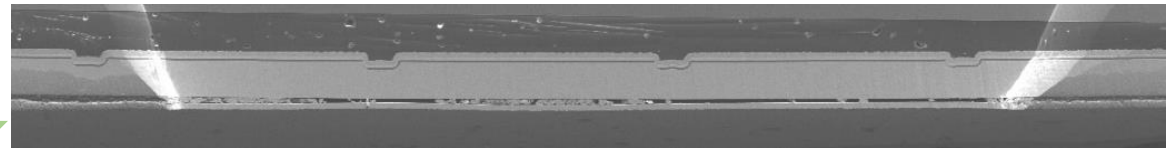
Filaments4Fusion

SUBRA
THEVA
I E E INSTITUTE OF ELECTRICAL
S A S ENGINEERING SAS

Relevant AC magnetization regime: $B_{ac} = B_{max} sin(2\pi f t)$

$2\pi f = \omega$

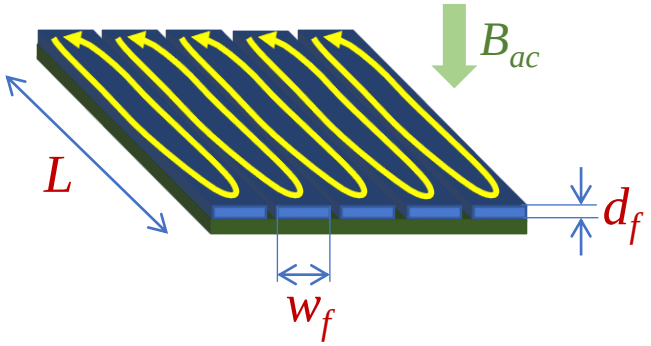
B_{ac}



Optimization of tape architecture

hysteresis loss reduced in proportion to N_f :

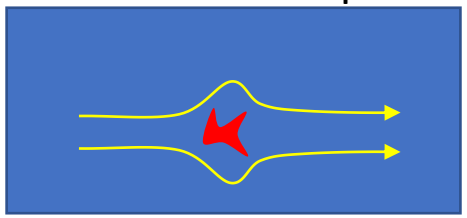
high-field approximation:



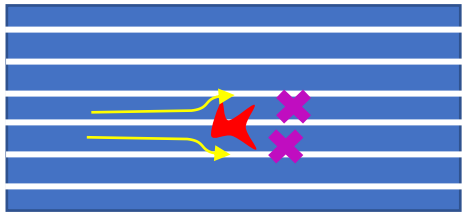
$$\frac{Q_h}{L} = B_{max} I_c w_f$$

current redistribution around a defect :

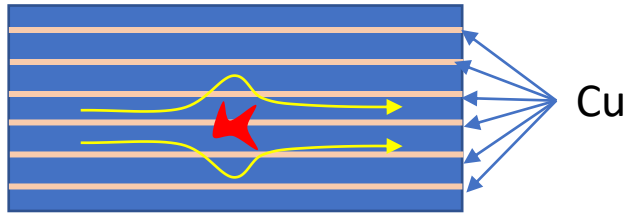
standard CC tape



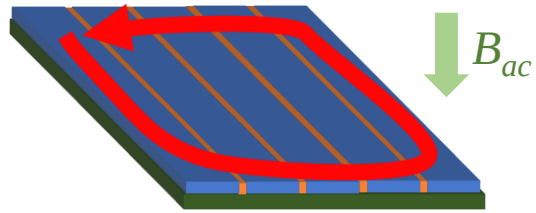
fiamentized CC tape



fiamentized CC tape
with Cu in gaps



circulation of currents through
metallic gaps: coupling AC loss



Optimization of tape architecture

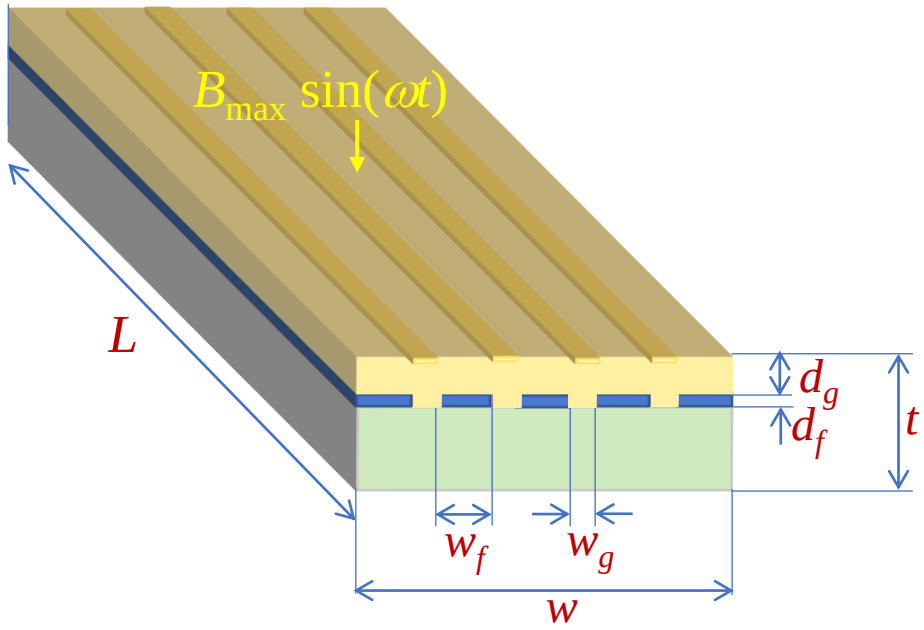
Sample characterisation:

- geometry: $L, w, t, w_f, w_g, d_g, d_f$

- materials: $I_{c,filament} = \frac{I_{c,tape}}{N_{filaments}}$

  gap resistivity ρ_g

  resistivity of metallic overlayer(s) ρ_e



AC loss reporting:

- magnetization loss: Q_m/L [J/m/cycle]

- AC susceptibility (imaginary part) : $\chi'' = \frac{Q_m}{Lwt}\frac{\mu_0}{\pi B_{max}^2}$

Experiments vs. theory

Hysteresis loss:

x-array of strips

Y Mawatari, Phys. Rev. B 54 (1996) 13215

$$\frac{Q_h}{L} = \frac{-4N_f s^2}{\pi\mu_0}\int_0^{B_{max}} (B_{max} - 2B) ln\left[1 - \frac{X}{cosh^2(B/B_0)}\right] dB$$

$$B_0 = \mu_0 I_{cf}/\pi w_f$$

$$X = \left[sin\left(\frac{\pi w_f}{2(w_f + w_g)}\right)\right]^2$$

Coupling loss:

effective medium approach

F Gömöry et al., Superconductivity 15 (2025) 100193

$$\frac{Q_c}{L} = \frac{\pi^3}{8} w^2 \frac{B_{max}^2}{\mu_0}\left[1 - \sqrt{\frac{\pi}{6\omega\tau}}\, tanh\left(\sqrt{\frac{6\omega\tau}{\pi}}\right)\right]\frac{1}{1+\omega^2\tau^2}$$

$$\tau = \frac{\mu_0}{3\pi}\frac{L^2}{\rho_\perp}\frac{d_g}{w}$$

$$\rho_\perp = \rho_g \frac{(N_f - 1)w_g}{w}$$

Eddy current loss:

metallic strip

E. H. Brandt, Phys. Rev. B 50 (1994) 13833

$$\frac{Q_e}{L} = \frac{\pi^2}{4} w^2 \frac{B_{max}^2}{\mu_0}\chi'' \qquad \chi'' = \left[\frac{3}{4b} + \frac{\pi^2 b}{ln(1+b^2) + 5{,}57}\right]^{-1}$$

$$b = \omega\tau_e$$

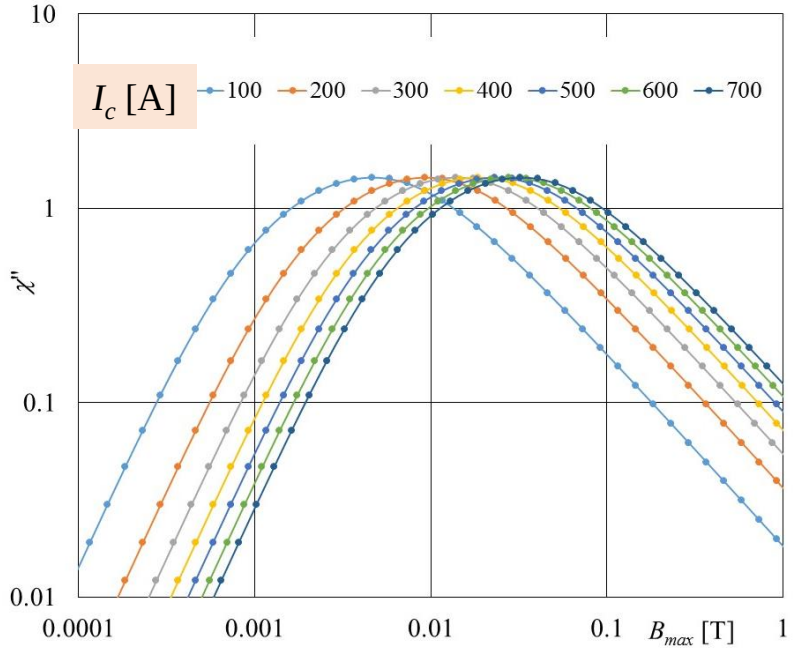
$$\tau_e = \frac{t_m w}{2}\frac{\mu_0}{\rho_e}$$

Hysteresis loss vs. filamentary architecture

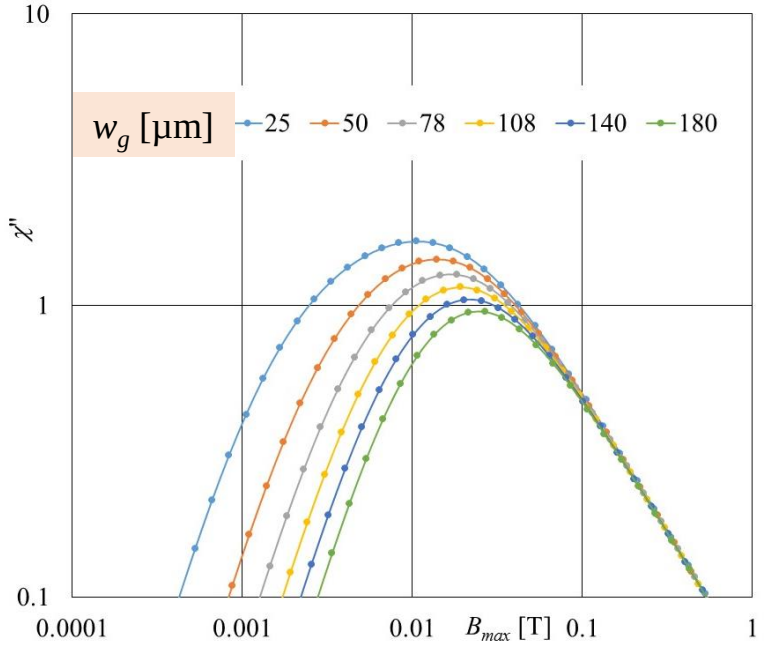
Y Mawatari, Phys. Rev. B 54 (1996) 13215

Tape 12 mm wide

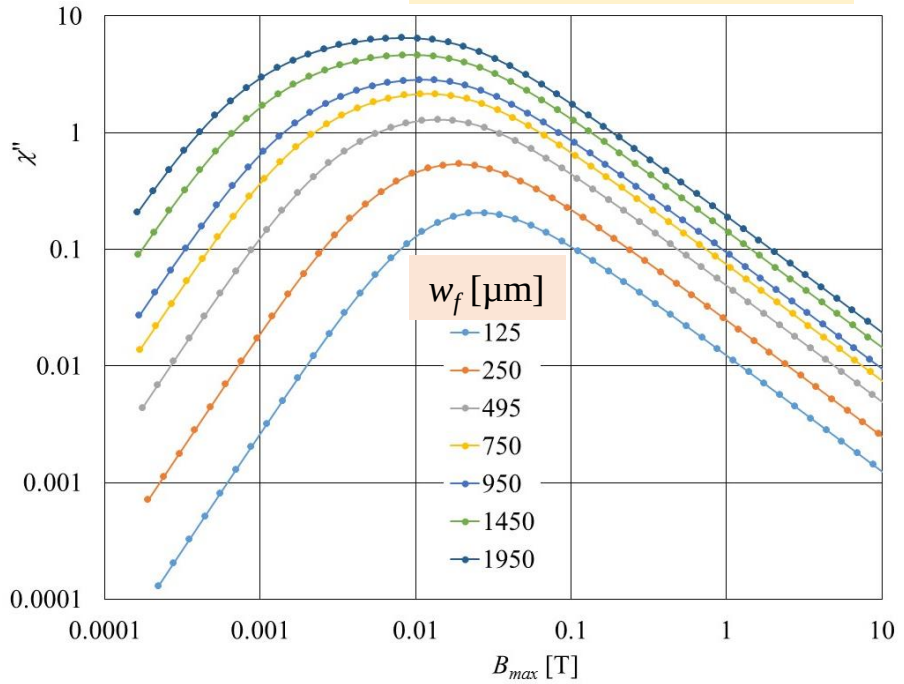
gaps 50 µm, filaments 495 µm



I_c = 300 A, filaments 495 µm



I_c = 300 A, gaps 50 µm



narrower filaments → lower hysteresis loss

Coupling loss vs. filamentary architecture

low frequency limit:
(practical use)

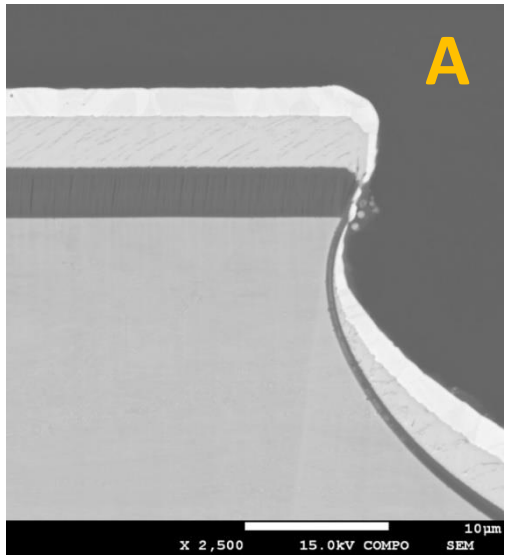
$$\lim_{\omega \to 0} \frac{Q_c}{L} = \frac{\pi}{12} w d_g B_{max}^2 \omega \frac{L^2}{\rho_\perp}$$

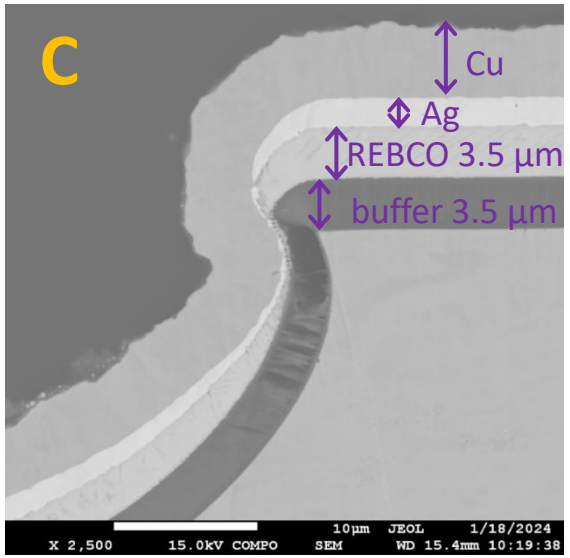
$$\rho_\perp = \rho_g \frac{(N_f - 1) w_g}{w_{tape}}$$ in reality a fitting parameter $\rho_g = k_g \rho_{Cu}$ $\rho_{Cu} = 2 \times 10^{-9}\ \Omega m$

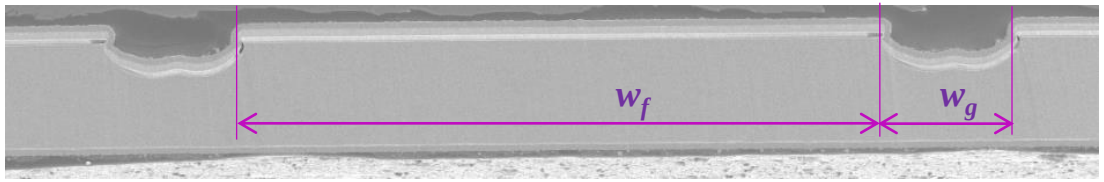
W J Carr Jr, Supercond. Sci. Technol. 20 (2007) 168

$$\lim_{\omega \to 0} \frac{Q_c}{V} = \frac{\pi}{12} B_{max}^2 \omega \frac{L^2}{\rho_\perp} = \frac{\pi}{12} B_{max}^2 \omega \frac{L^2 w}{(N_f - 1)} \frac{1}{\rho_g w_g}$$

Tapes 12 mm wide – filament width & metallization

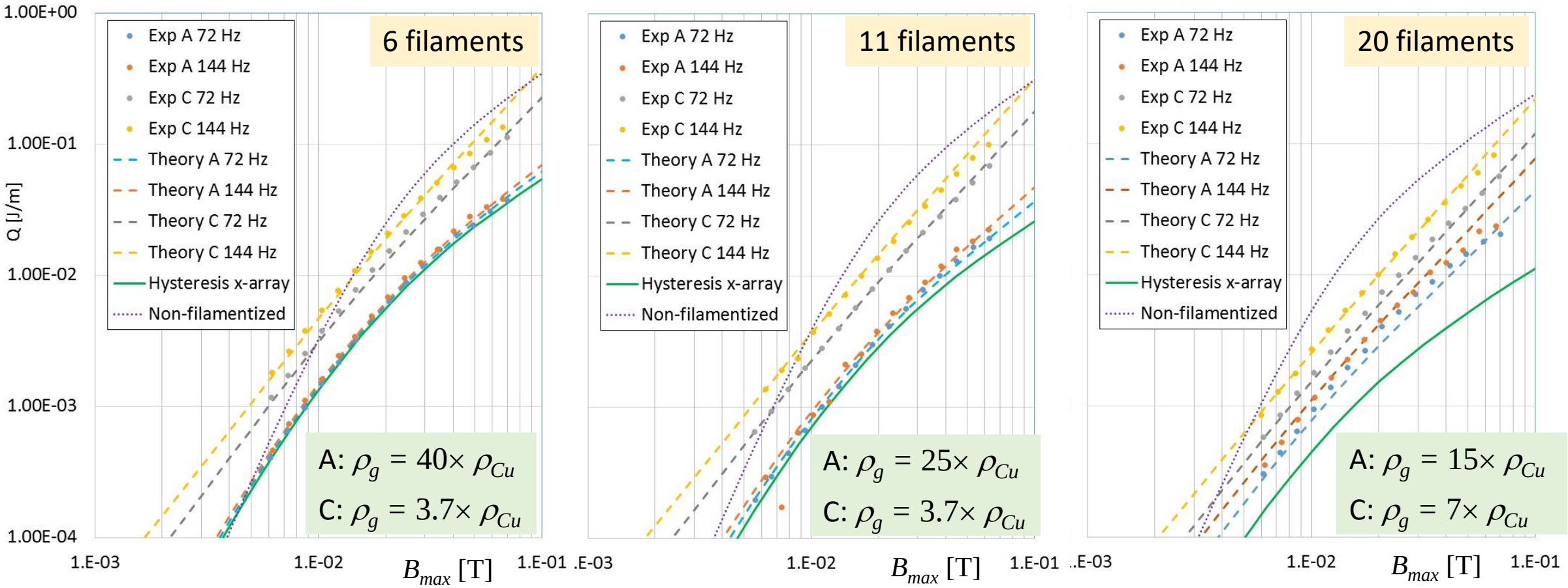






Sample	N_f	w_f [mm]	w_g [mm]	Cu [µm]	I_c [A]
A-2	6	1.82	0.19	0	340
C-2	6	1.82	0.19	3	340
A-1	11	0.98	0.12	0	300
C-1	11	0.98	0.12	3	300
A-05	20	0.55	0.05	0	220
C-05	20	0.55	0.05	3	220

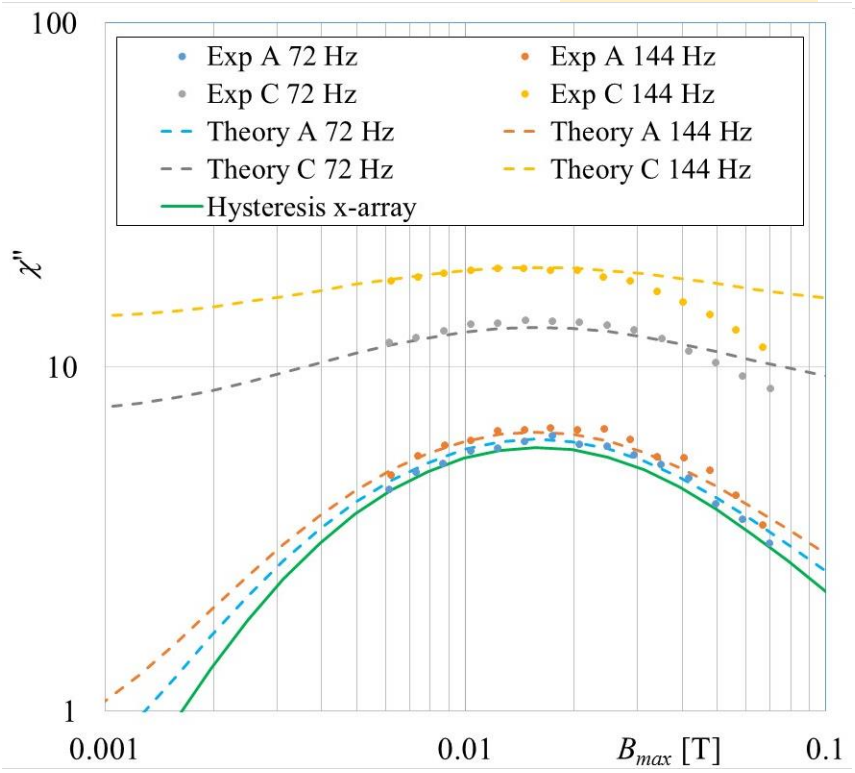
Tapes 12 mm wide – filament width & metallization



$\rho_{Cu} = 2\times10^{-9}\ \Omega$m

Tapes 12 mm wide – filament width & metallization

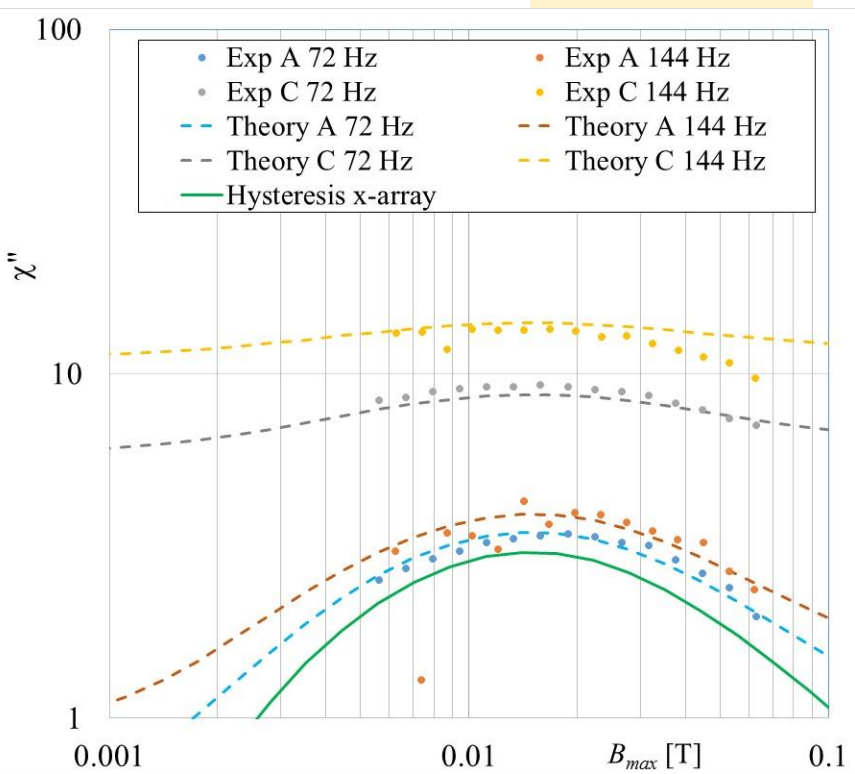
6 filaments



A: $\rho_g = 40\times \rho_{Cu}$

C: $\rho_g = 3.7\times \rho_{Cu}$

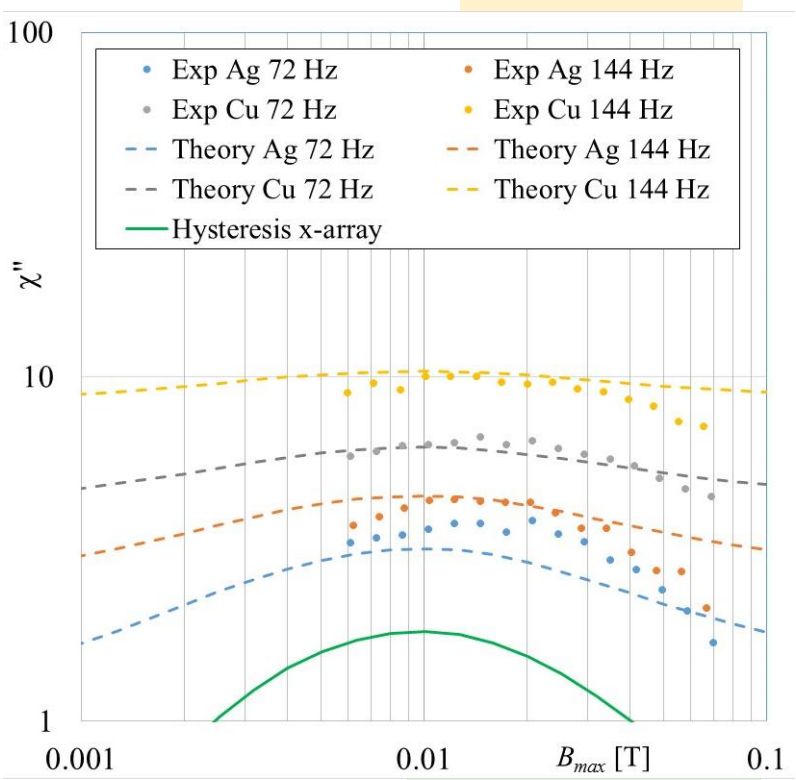
11 filaments



A: $\rho_g = 25\times \rho_{Cu}$

C: $\rho_g = 3.7\times \rho_{Cu}$

20 filaments



A: $\rho_g = 15\times \rho_{Cu}$

C: $\rho_g = 7\times \rho_{Cu}$

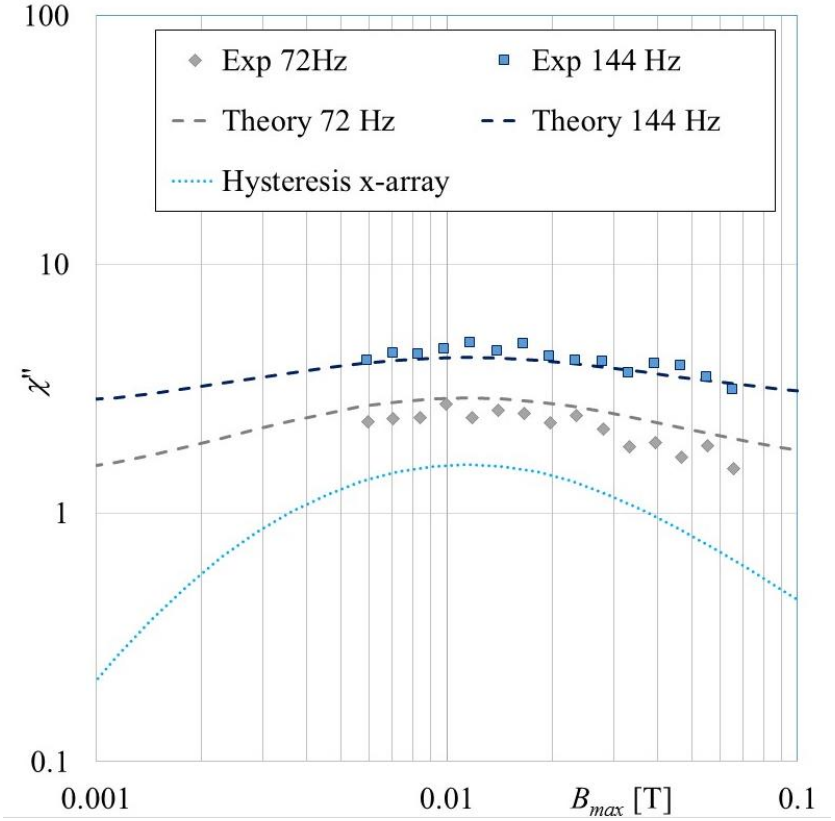
$\rho_{Cu} = 2\times10^{-9}\ \Omega$m

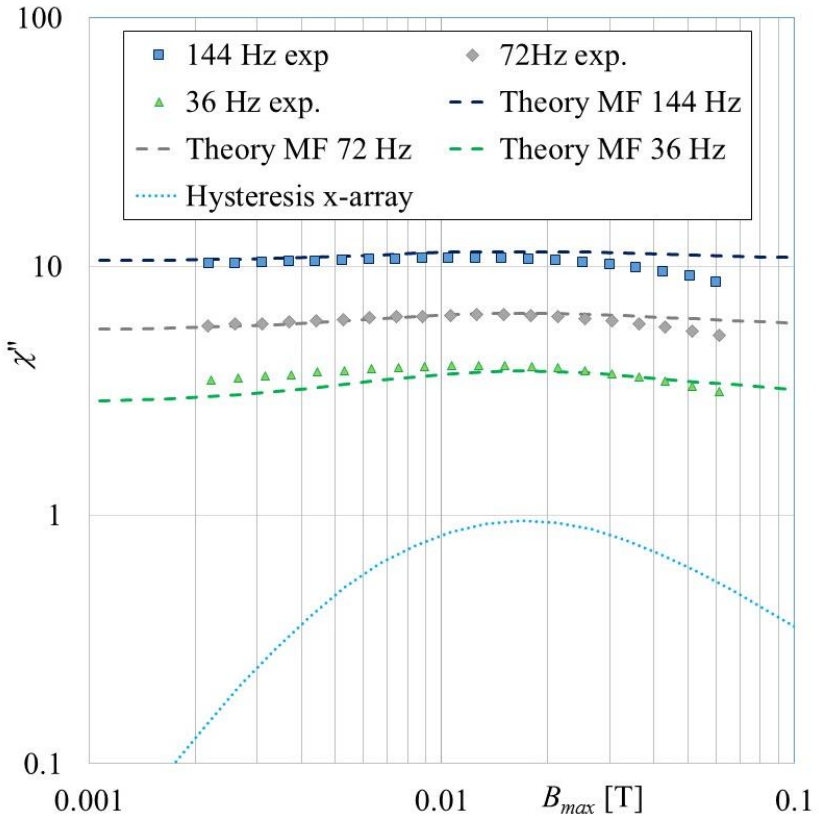
Tapes 12 mm wide, 500 µm filaments – gap width & metallization

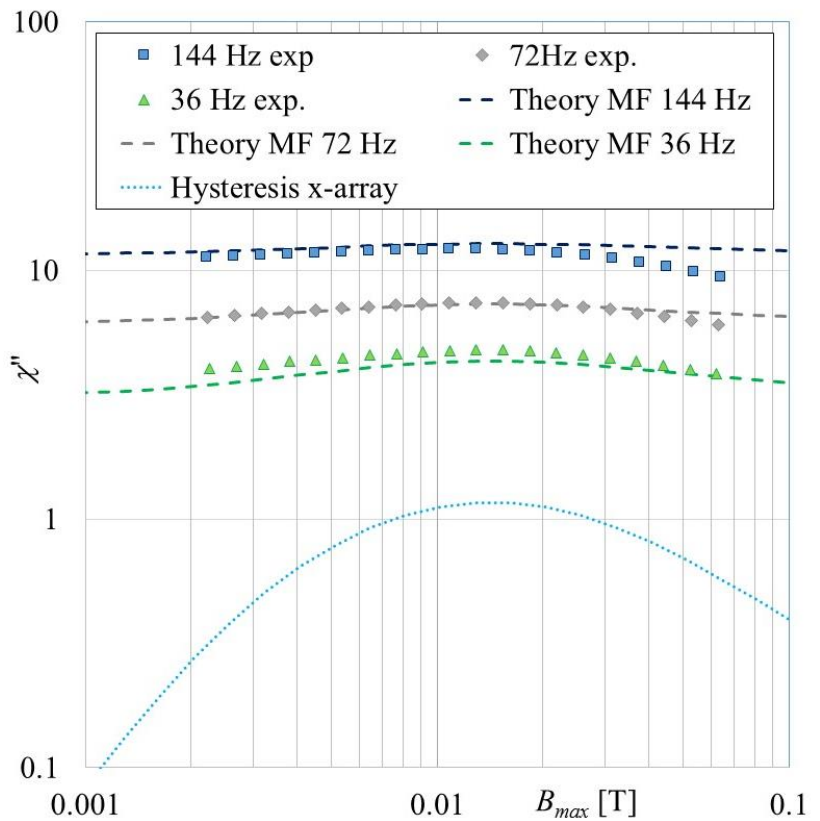
Sample	w_f [µm]	w_g [µm]	Ag [µm]	Cu [µm]	d_g [µm]	k_g	I_c [A]
B-3	500	80	1.3	3.9	5.2	12	244
B-4	498	116	1.9	14.7	16.6	3.2	264
B-5	484	69	1.35	9.2	10.55	3.3	260

$$\lim_{\omega \to 0} \frac{Q_c}{L} \propto \frac{d_g}{\rho_g w_g}$$

$$\rho_g = k_g \rho_{Cu} \qquad \rho_{Cu} = 2\times10^{-9}\ \Omega\text{m}$$

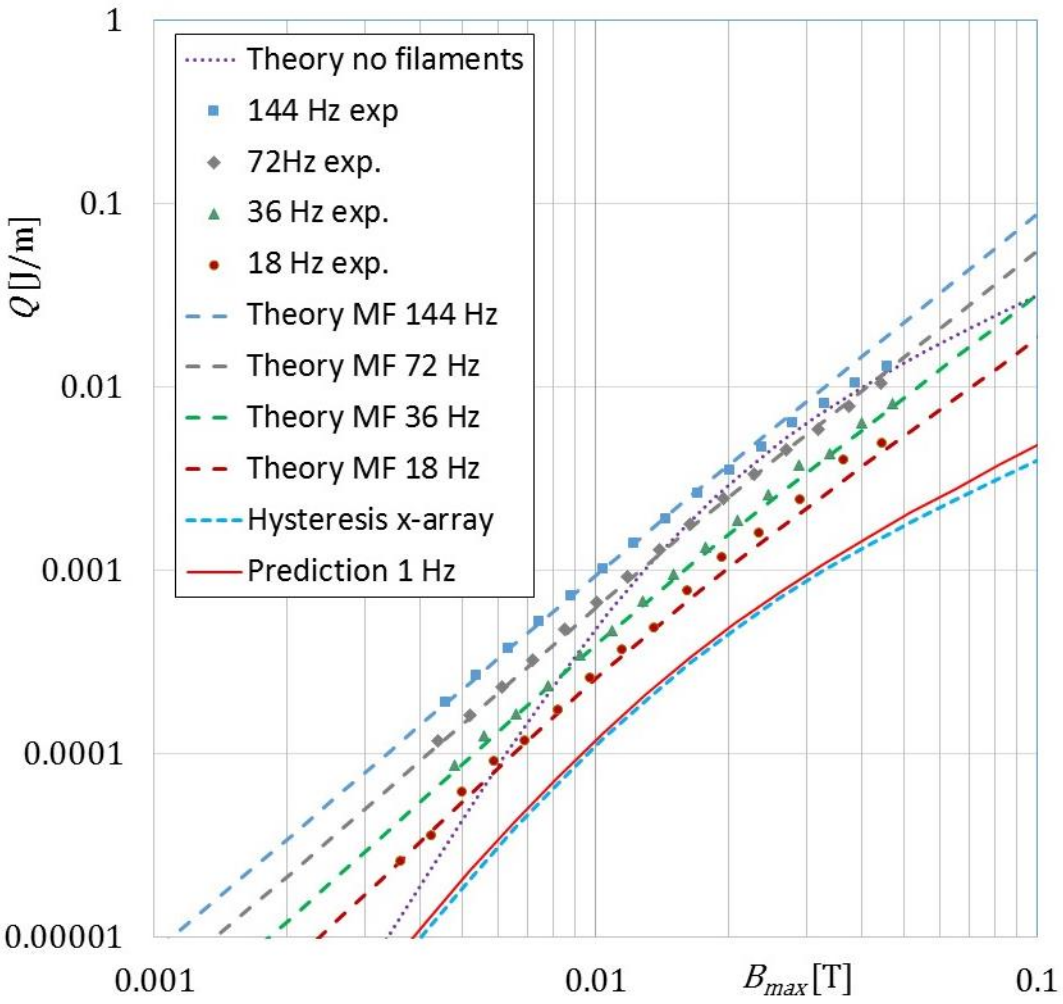






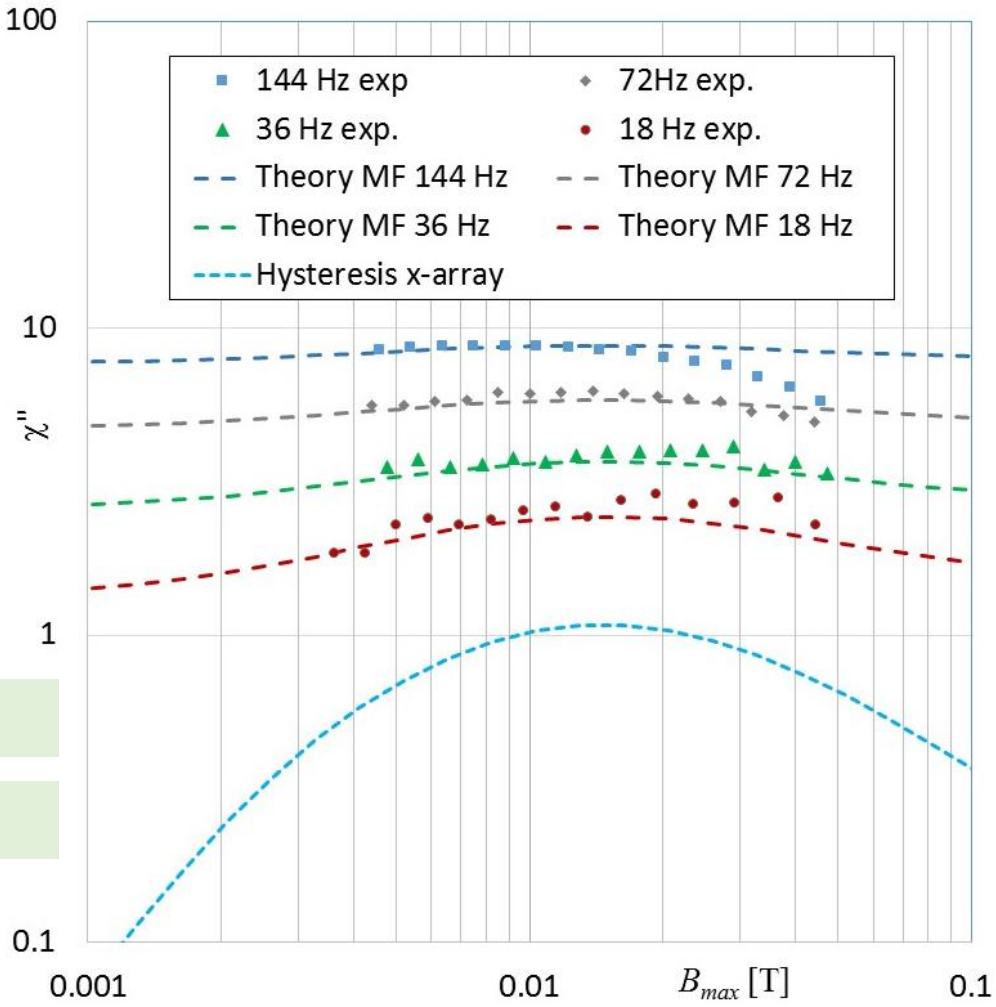
Tapes 4 mm wide

7 filaments 500 μm, 3.56 μm Ag + 13.7 μm Cu, I_c = 90 A



$\rho_g = 5.6\times \rho_{Cu}$

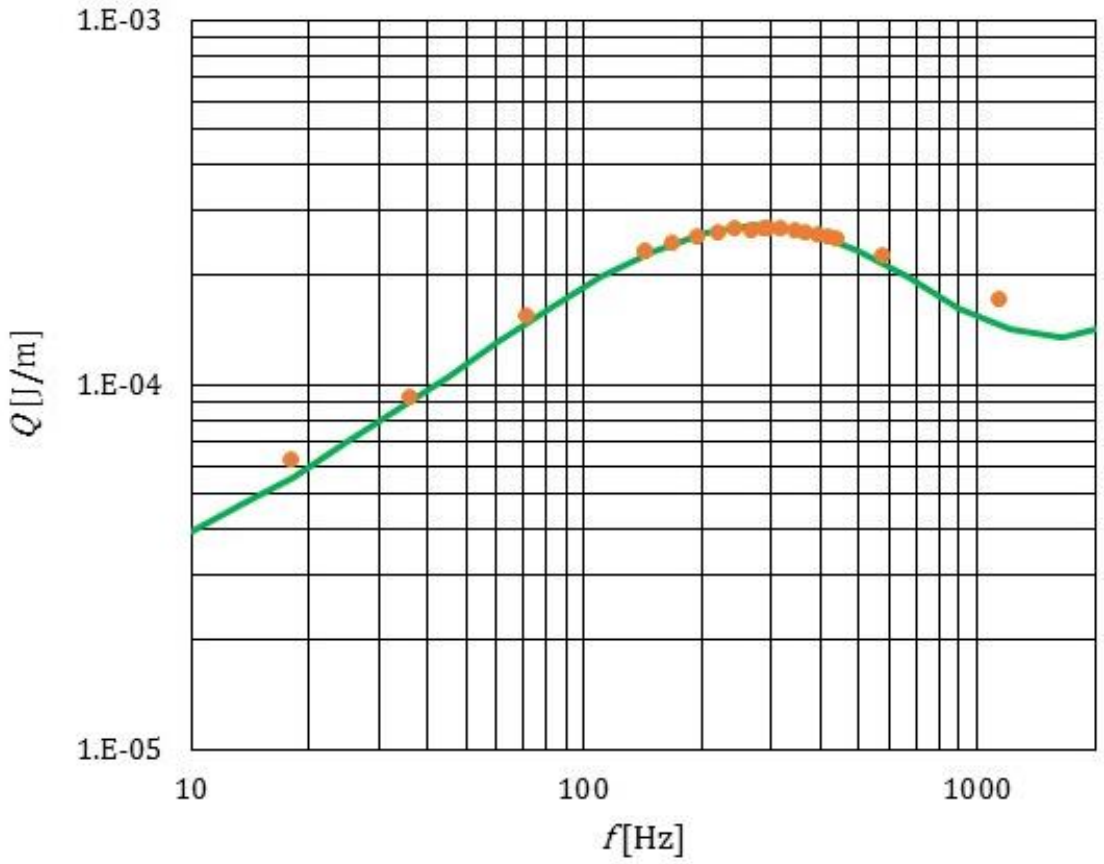
$\rho_{eddy} = 1\times \rho_{Cu}$



Tapes 4 mm wide

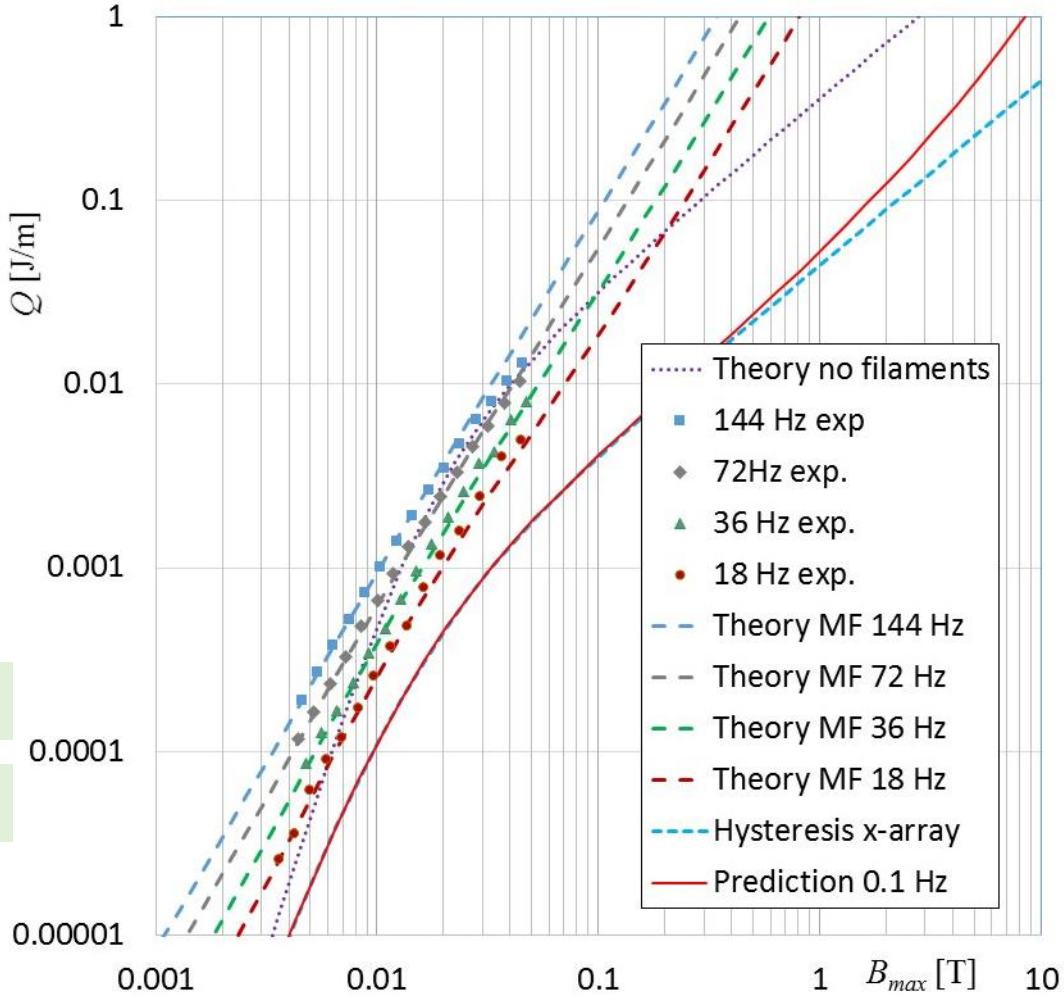
7 filaments 500 μm, 3.56 μm Ag + 13.7 μm Cu, I_c = 90 A

B_{max} = 5 mT



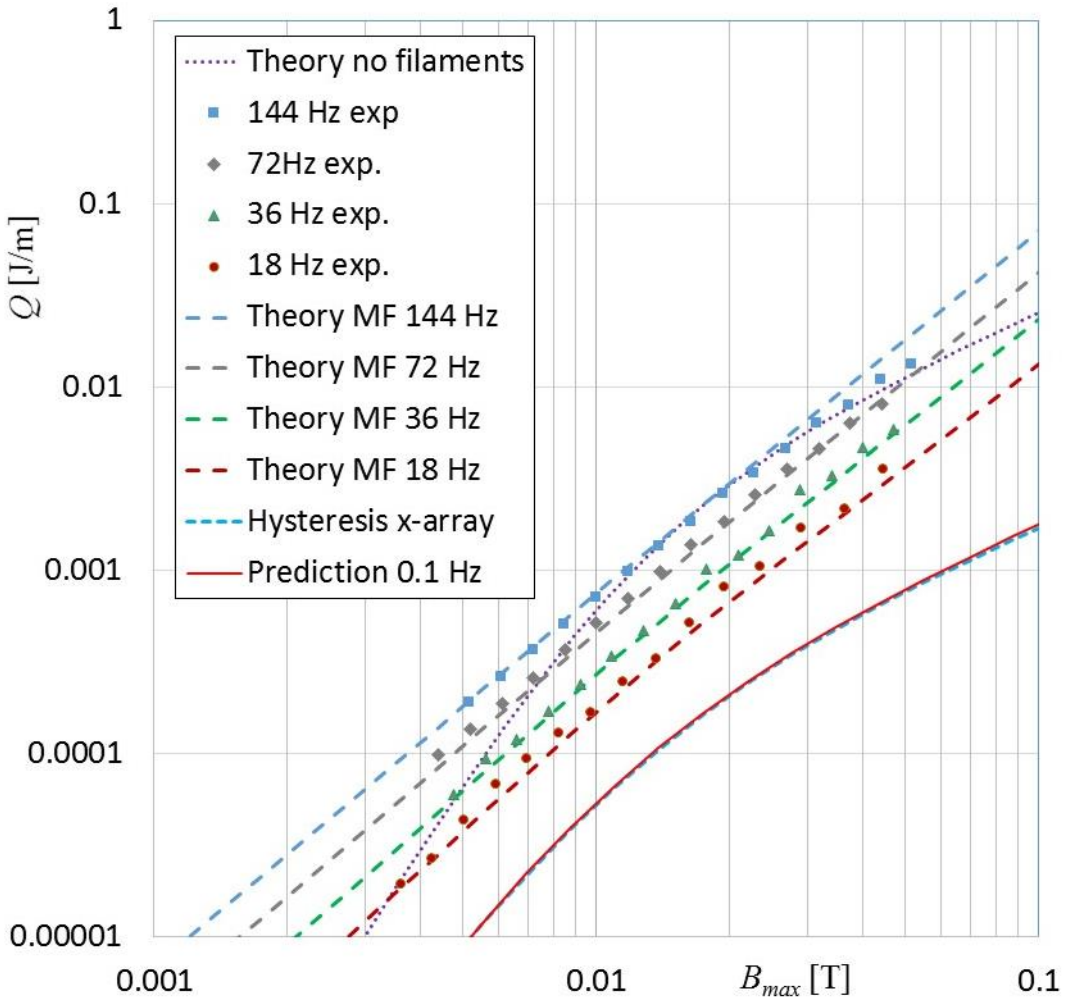
$\rho_g = 5.6\times \rho_{Cu}$

$\rho_{eddy} = 1\times \rho_{Cu}$



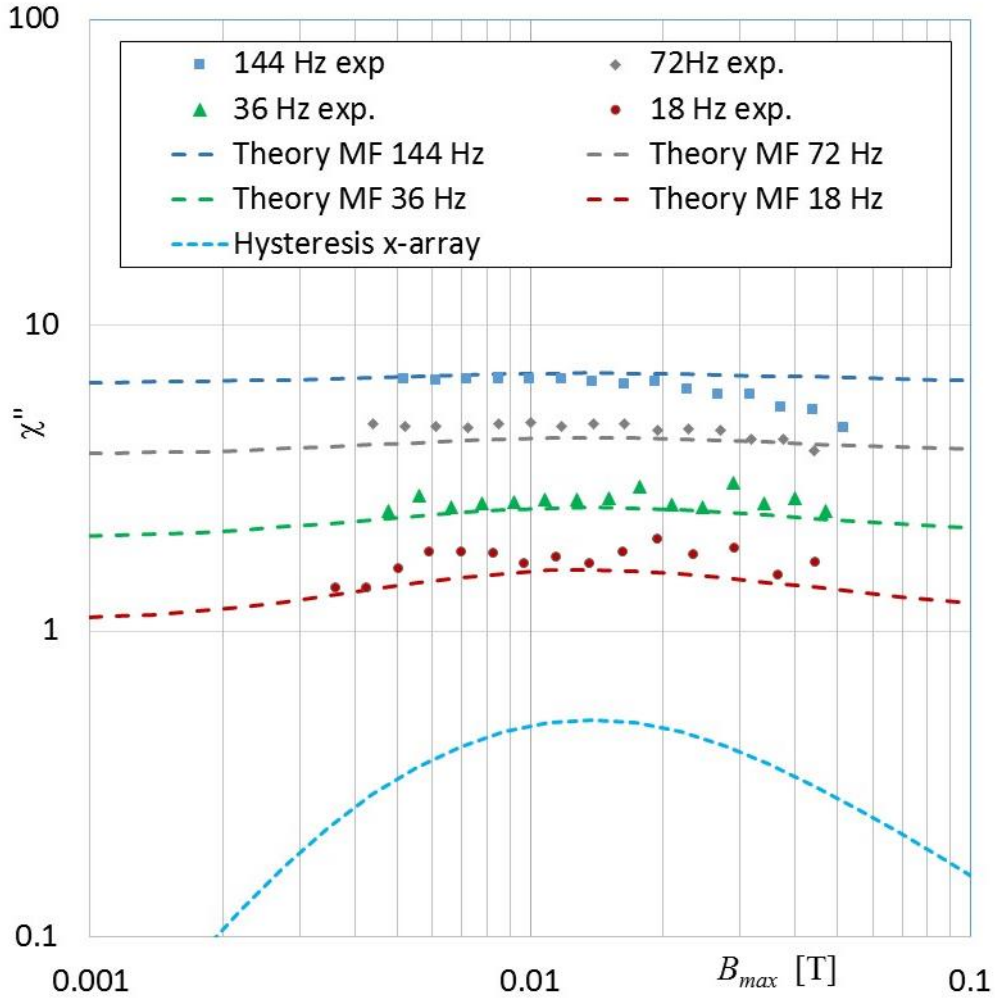
Tapes 4 mm wide

12 filaments 250 μm, 4.3 μm Ag + 13.3 μm Cu, I_c = 70 A



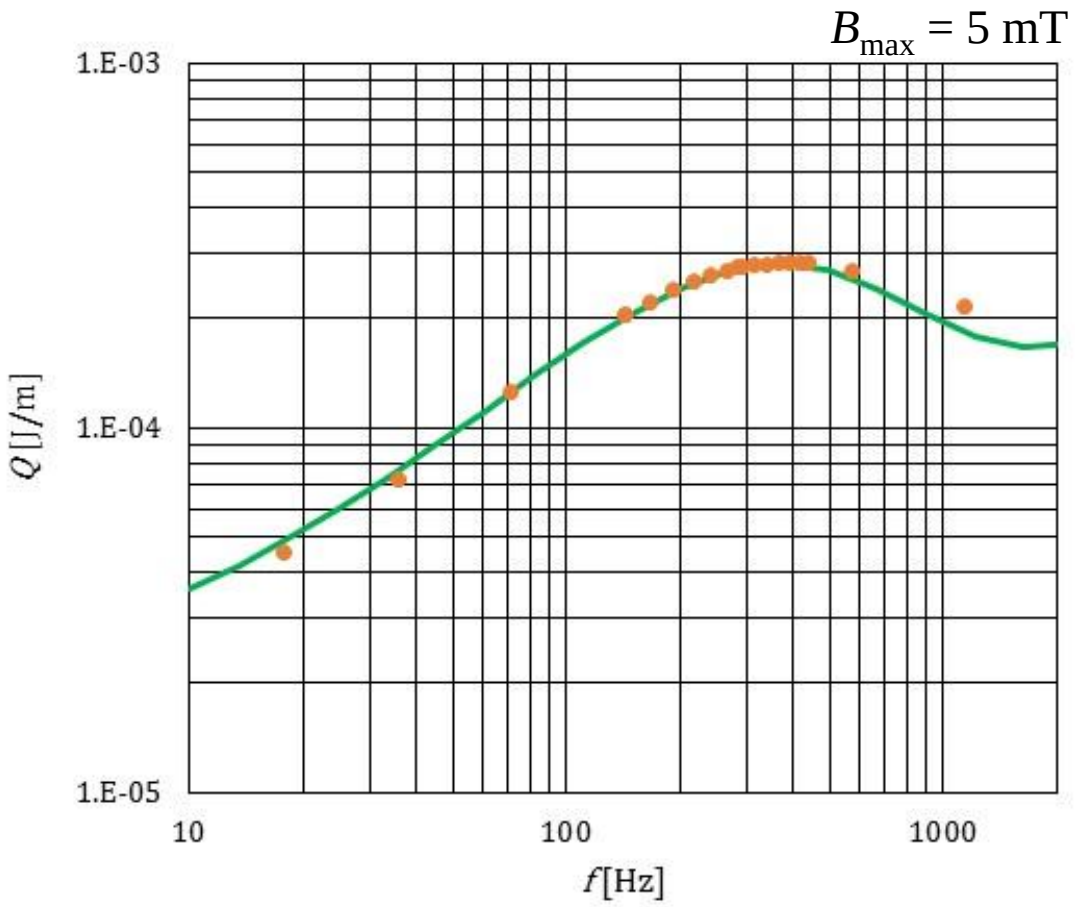
$\rho_g = 6 \times \rho_{Cu}$

$\rho_{eddy} = 1 \times \rho_{Cu}$



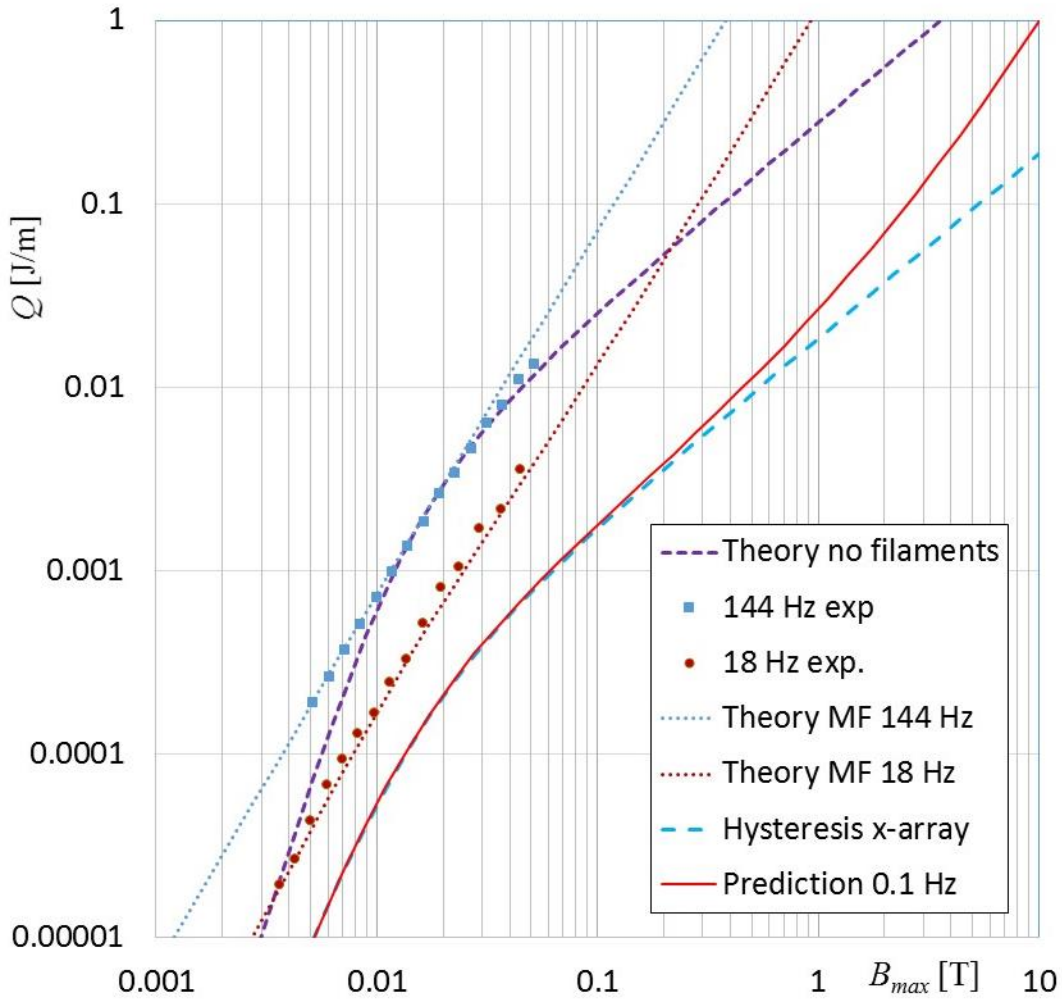
Tapes 4 mm wide

12 filaments 250 μm, 4.3 μm Ag + 13.3 μm Cu, I_c = 70 A



$\rho_g = 6 \times \rho_{Cu}$

$\rho_{eddy} = 1 \times \rho_{Cu}$



Conclusions and outlook

Magnetization loss of filamentized tapes prepared by 2LUPS technology in 12 mm and 4 mm versions:

- controllable by tape architecture
- predictable by theory (transverse resistivity remaining the only fitting parameter)

Outlook for 2026-27:

- manufacturing of laboratory models of round cables from MF tapes
- experimental testing of magnetization loss, verification of theoretical predcitions