Design Criteria for Warm Temperature Dielectric Superconducting dc Cables: Impact of Co-Pole Magnetic Fields

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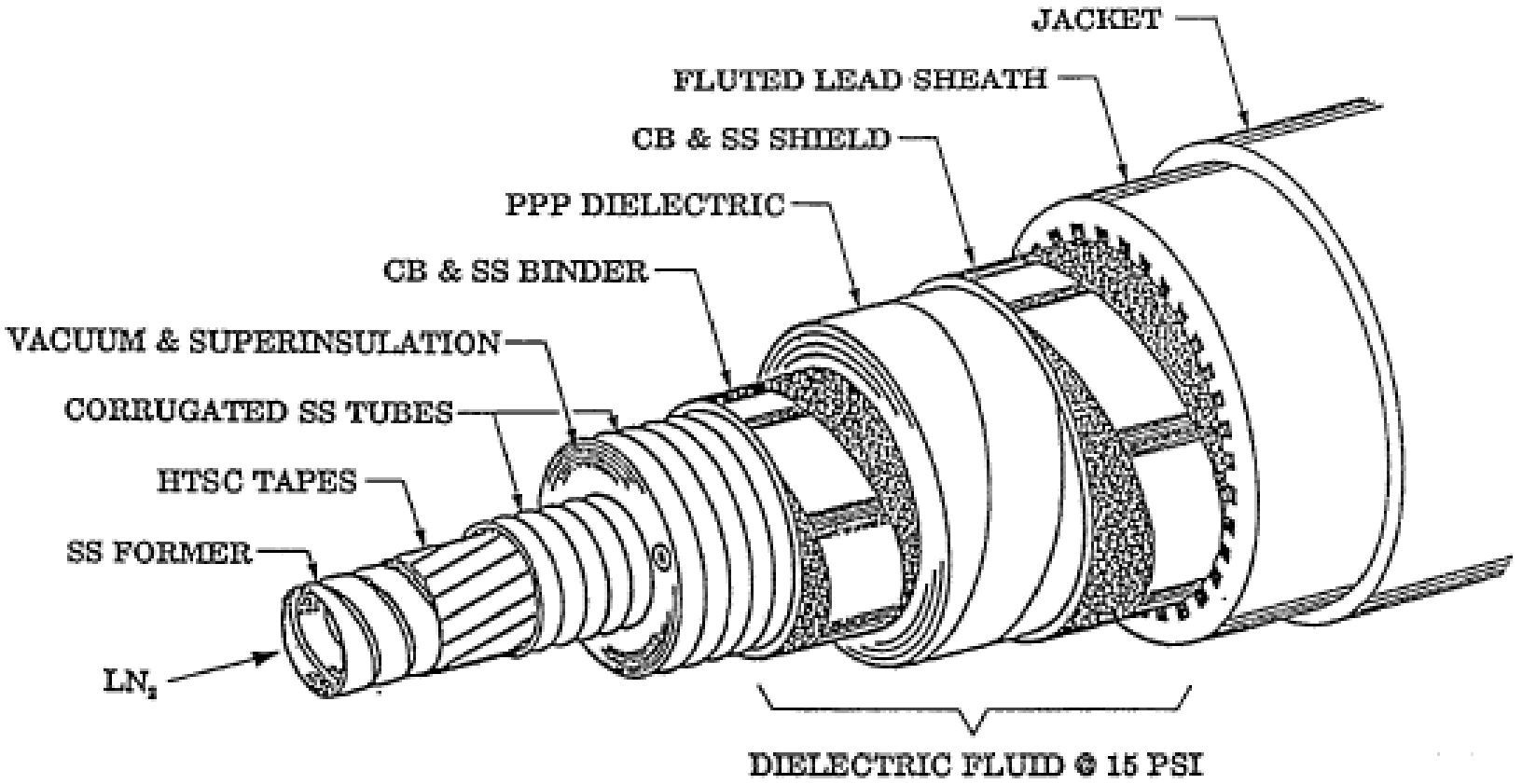
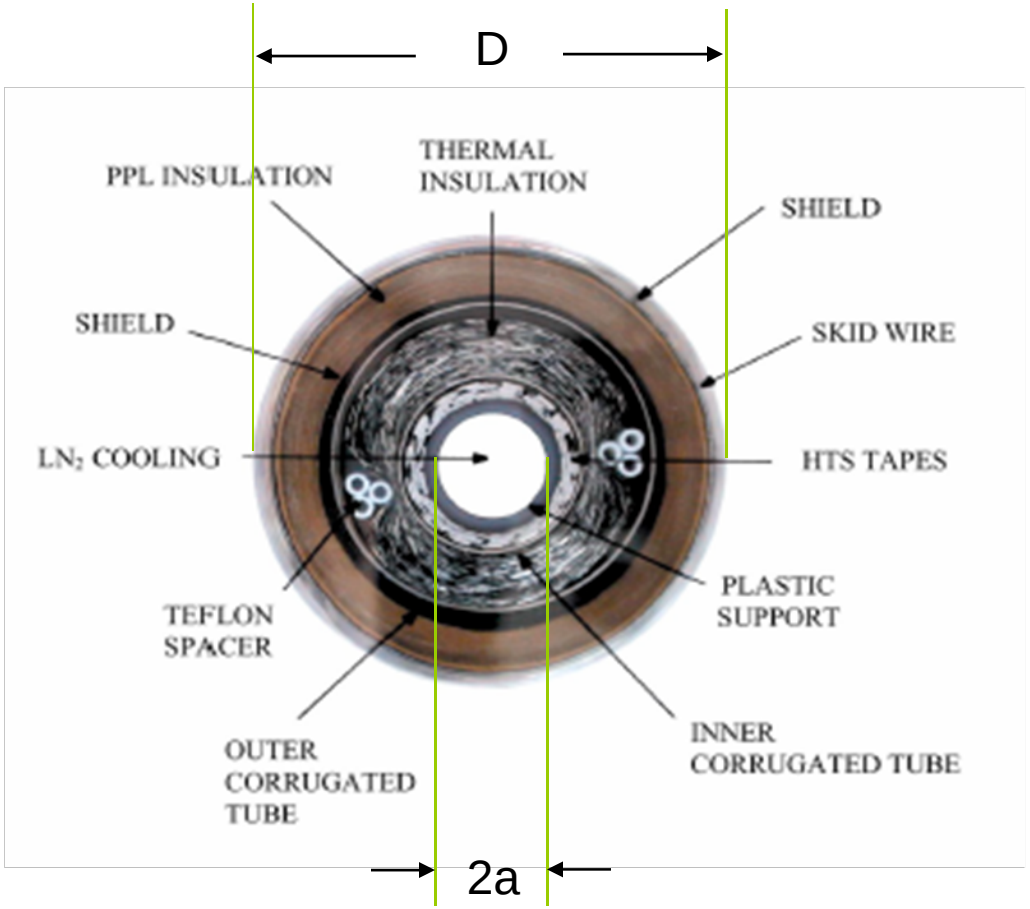
18 September 2007

EPRI WTD Cable - 1994



EPRI/Pirelli WTD Prototype



Past WTD Cable Demonstration Specifications

Cable Project	V (kV)	I (A)	D (mm)	a (mm)	d (mm)
EPRI/Pirelli	115	2000	88.1	18.6	95
DTE Frisbie	25	2400	88.1	18.6	254
Puji Substation	35	2000	112.0	17.5	1000

Puji Substation - Kunming

Detroit – Edison (Frisbie)

Inter-Conductor Magnetic and Force Fields

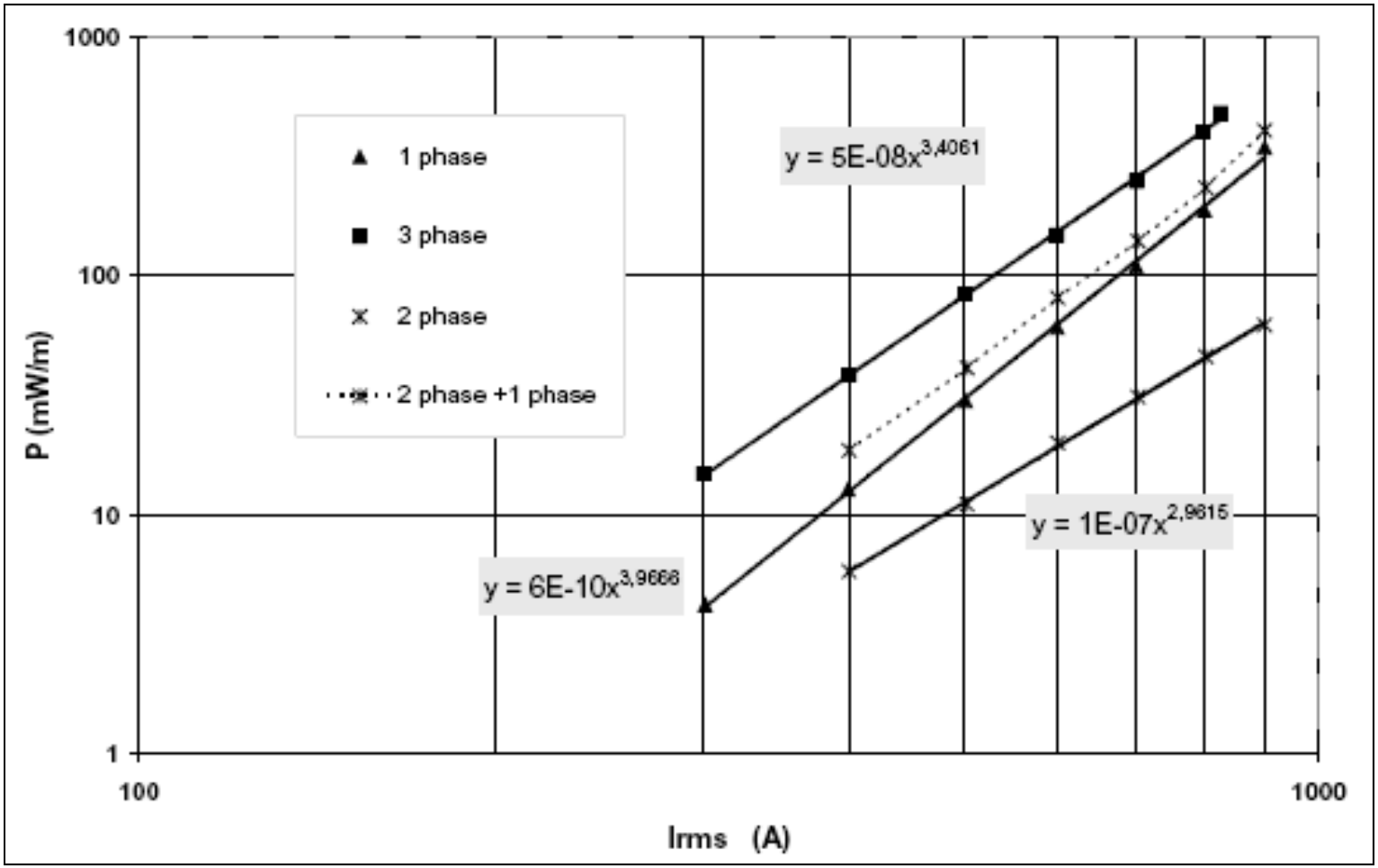
$$B = \frac{\mu_0}{2\pi}\frac{I}{r}$$

Ampere's Law

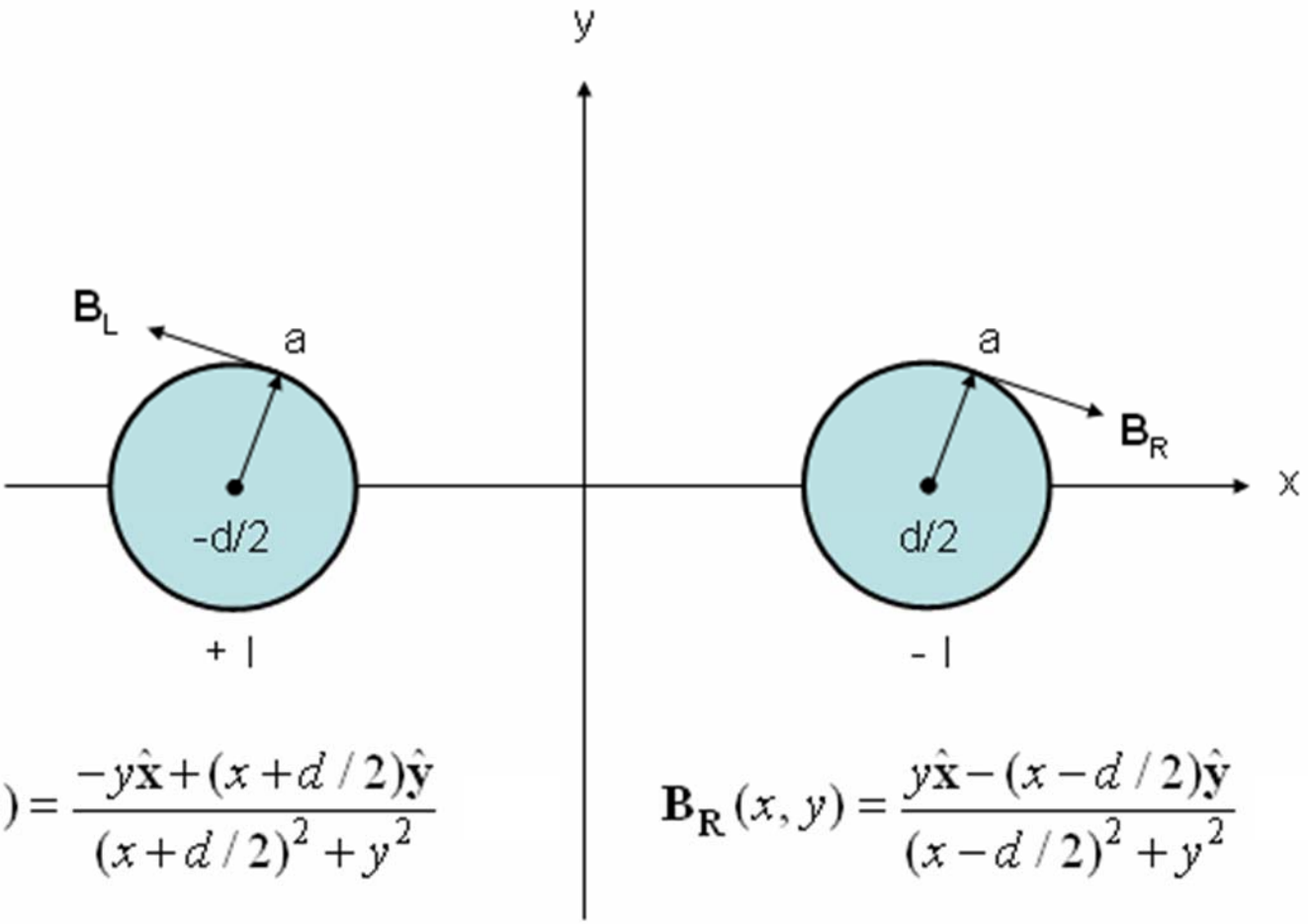
$$\frac{dF}{dl} = \frac{\mu_0}{2\pi}\frac{I^2}{r}$$

Lorentz Force

Co-Phase Induced ac Losses



Two Conductor Biot-Savart Equations

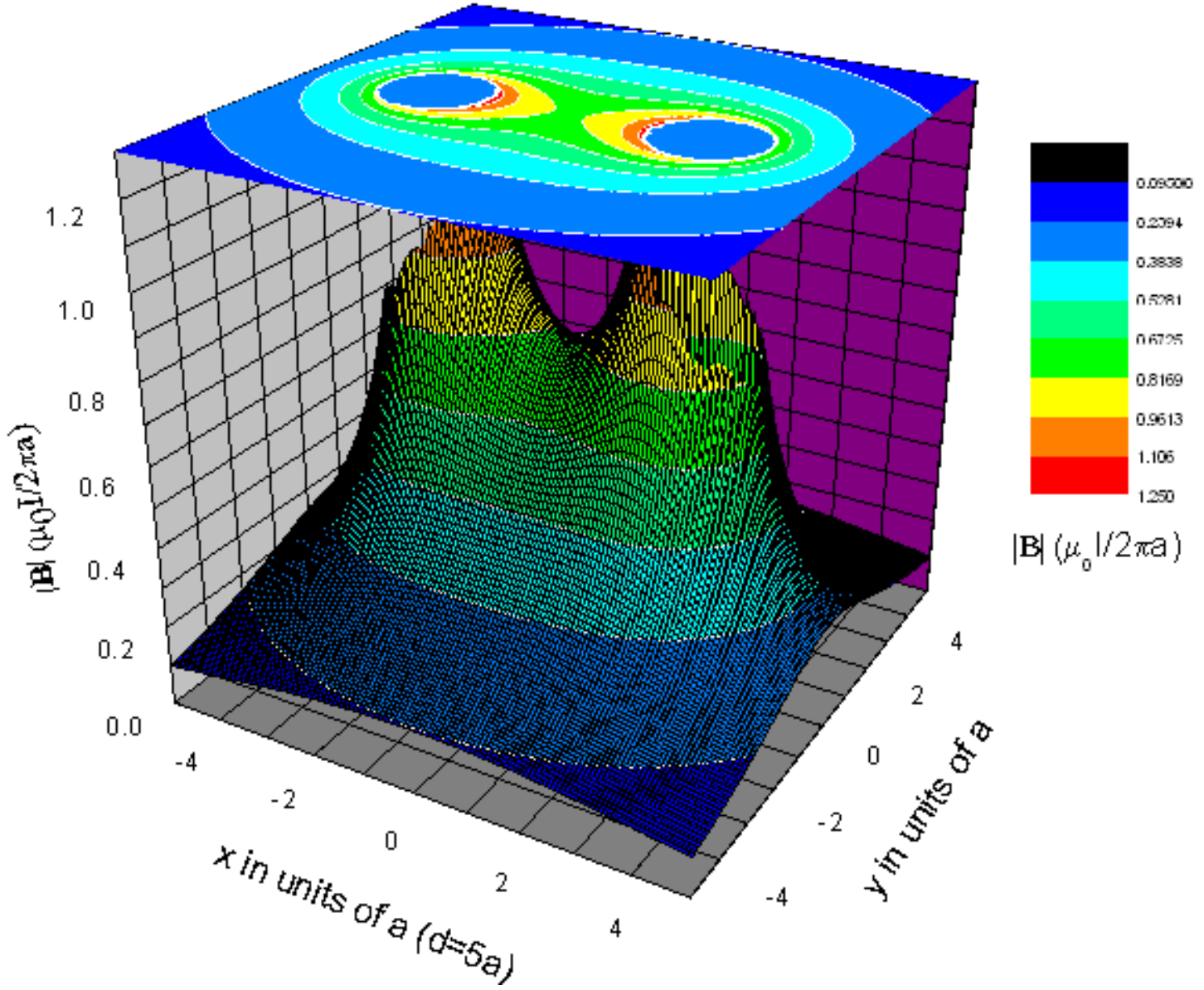


$$\mathbf{B_L}(x,y) = \frac{-y\hat{\mathbf{x}} + (x + d/2)\hat{\mathbf{y}}}{(x + d/2)^2 + y^2}$$

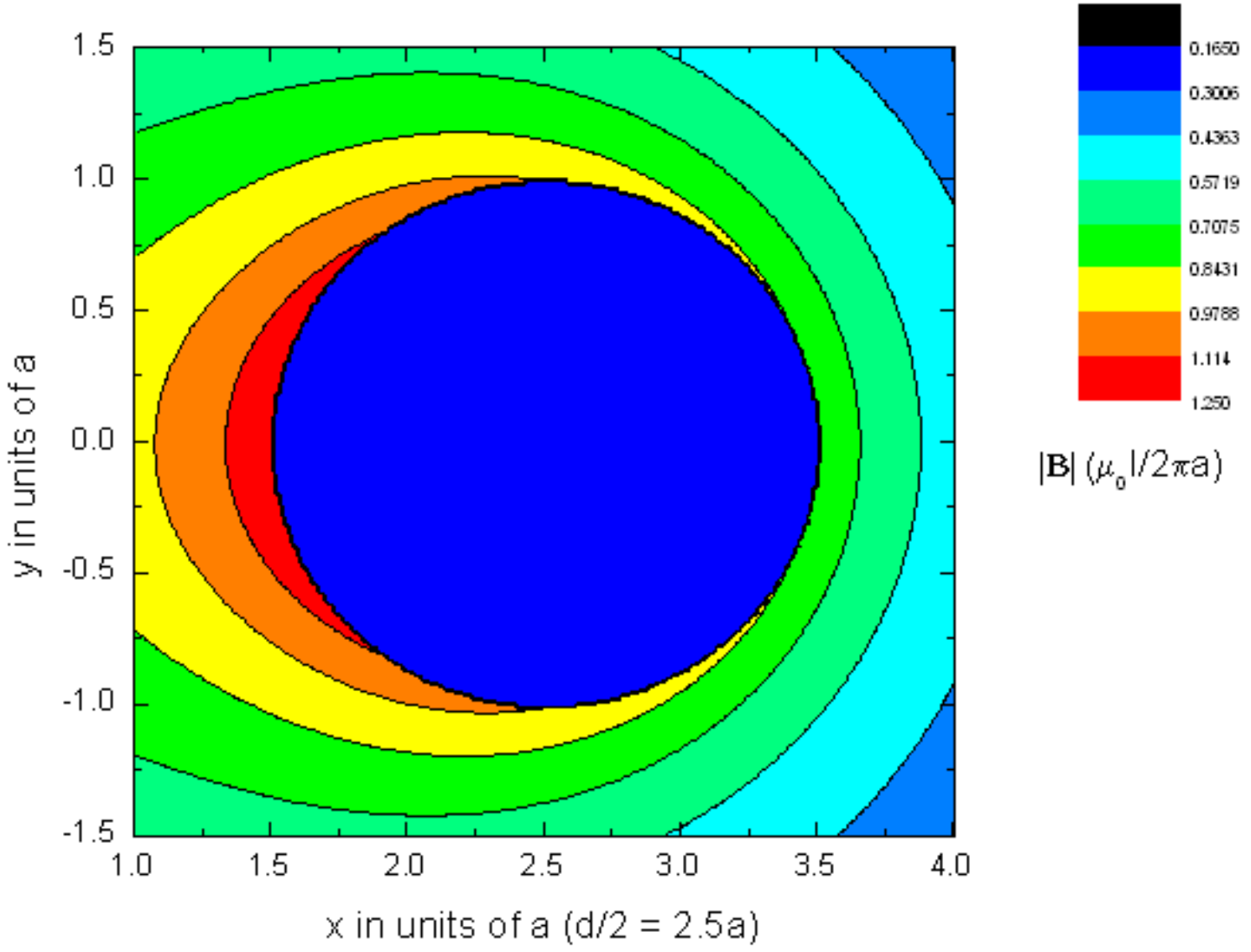
$$\mathbf{B_R}(x,y) = \frac{y\hat{\mathbf{x}} - (x - d/2)\hat{\mathbf{y}}}{(x - d/2)^2 + y^2}$$

$$\mathbf{B}(x,y) = \mathbf{B_L}(x,y) + \mathbf{B_R}(x,y)$$

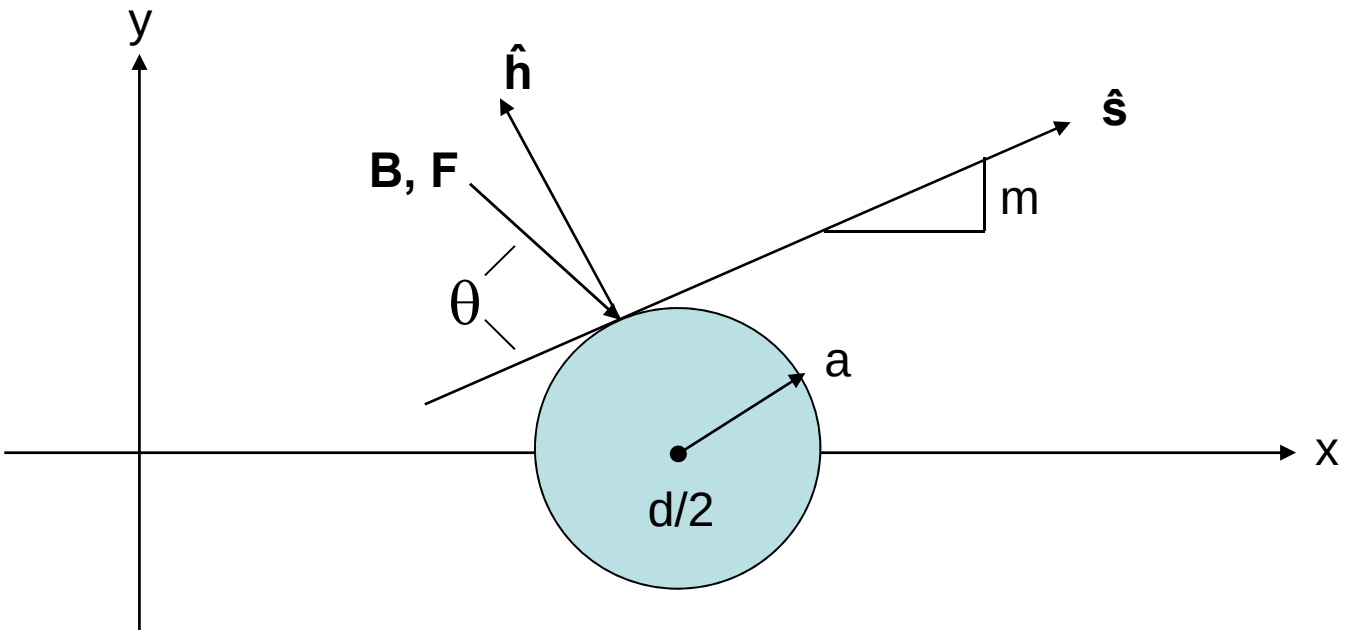
Field – Force Distributions



RH Conductor Field – Force Contours



Incidence Angle and Magnitude of Inter-Conductor Field and Force



$$y = \pm\sqrt{a^2 + (x - d/2)^2}$$

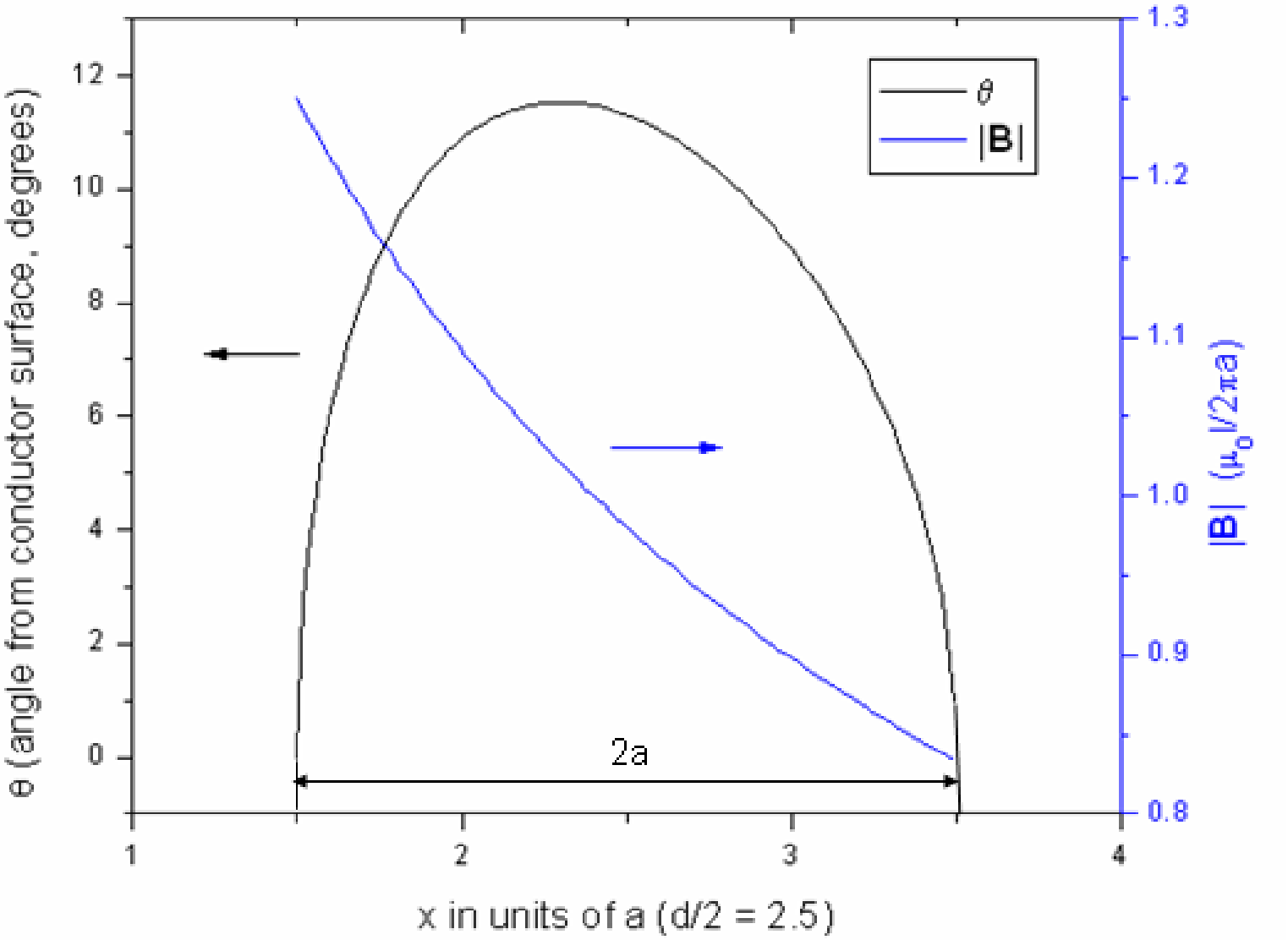
$$m = \pm\frac{dy}{dx} = \frac{-(x - d/2)}{y}$$

$$\hat{\mathbf{s}} = \frac{\hat{\mathbf{x}} + m\hat{\mathbf{y}}}{\sqrt{1+m^2}}, \quad \hat{\mathbf{h}} = \frac{-m\hat{\mathbf{x}} + \hat{\mathbf{y}}}{\sqrt{1+m^2}}$$

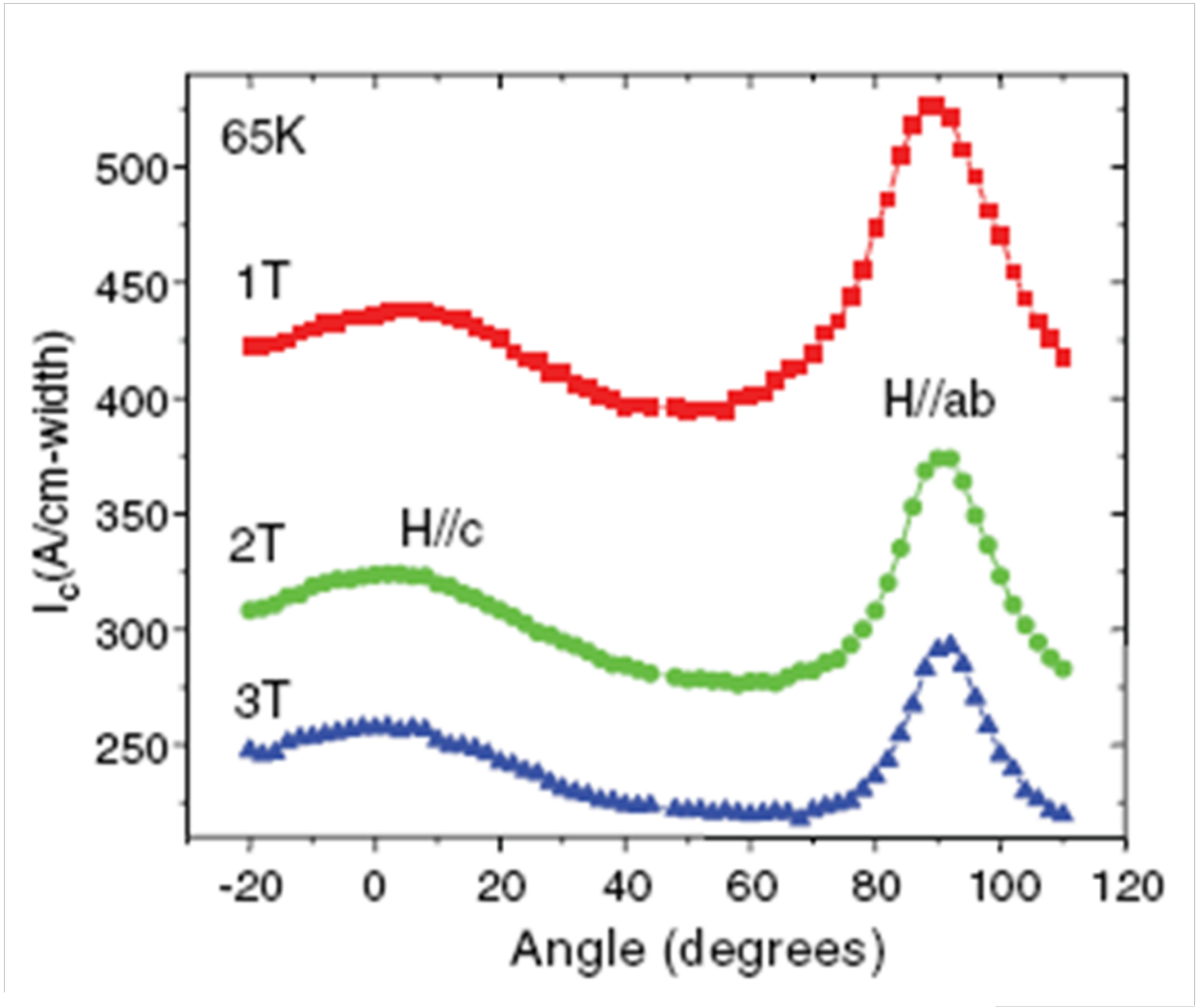
$$\theta = \cos^{-1}\frac{\mathbf{B}\cdot\hat{\mathbf{s}}}{|\mathbf{B}|}$$

$$F_h = \mathbf{F}\cdot\hat{\mathbf{h}}$$

Field Angle and Magnitude Incident on RH Conductor



Ic Dependence on Field Angle of Incidence for RABiTS YBCO Films



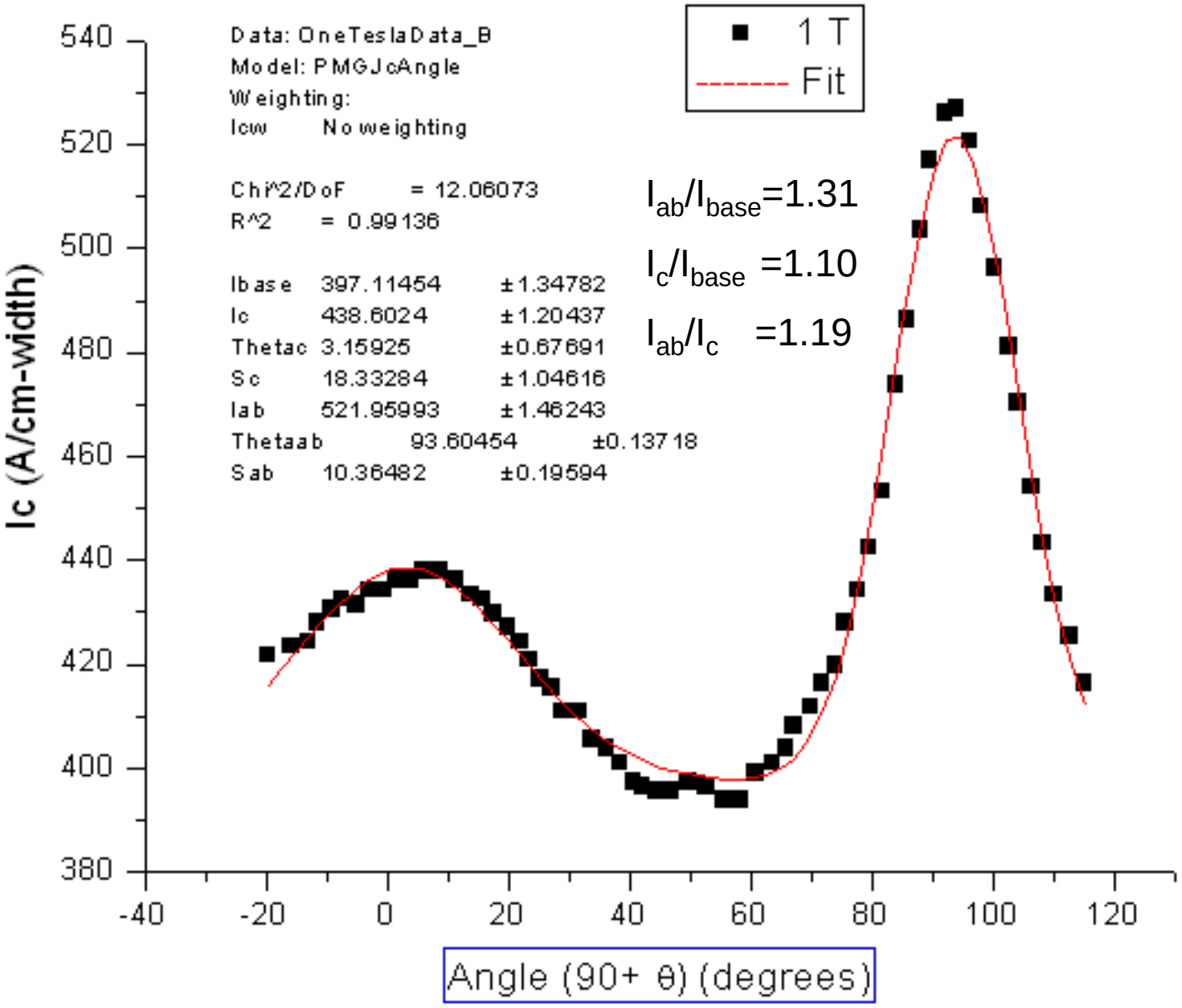
Kang S, *et al.* 2006 *Science* **311** 1911

Gaussian-Based Fit

$$I_{C-W}(\theta) = G_c(\theta) I_{base} + (I_c - I_{base}) G_c(\theta) + (I_{ab} - I_{base}) G_{ab}(\theta) \ ,$$

where $G_n(\theta)$ has the form

$$G_n(\theta) = \exp[-(\theta - \theta_n)^2 / 2\sigma_n^2] \ .$$


Data: OneTeslaData_B
Model: PMGJcAngle
Weighting:
Icw No weighting
Chi^2/DoF = 12.06073
R^2 = 0.99136
Ibase 397.11454 ±1.34782
Ic 438.6024 ±1.20437
Thetac 3.15925 ±0.67691
Sc 18.33284 ±1.04616
Iab 521.95993 ±1.46243
Thetaab 93.60454 ±0.13718
Sab 10.36482 ±0.19594
1 T
Fit
I_{ab}/I_{base}=1.31
I_c/I_{base} =1.10
I_{ab}/I_c =1.19
Ic (A/cm-width)
Angle (90+ θ) (degrees)
540
520
500
480
460
440
420
400
380
-40
-20
0
20
40
60
80
100
120

Magnetic fields and forces between WTD cables as a function of separation

Cable Project	I (A)	d/a	B(a) (T)	B(d) (T)	B(d)/B(a)	**dF/dl (g/m)**
EPRI/Pirelli	2000	5.11	0.022	0.004	0.20	0.86
DTE Frisbie	2400	13.66	0.026	0.002	0.07	0.77
Puji Substation	2000	57.14	0.023	0.0004	0.02	0.08
EPRI/Pirelli	10000	5.11	0.108	0.021	0.20	21.5
DTE Frisbie	10000	13.66	0.108	0.008	0.07	8.0
Puji Substation	10000	57.14	0.114	0.002	0.02	2.1
EPRI/Pirelli	25000	5.11	0.269	0.053	0.20	134.1
DTE Frisbie	25000	13.66	0.269	0.020	0.07	78.7
Puji Substation	25000	57.14	0.286	0.005	0.02	12.7

Conclusions & Homework

- Critical state effects arising from mutual co-pole magnetic fields are manageable, especially with the development of isotropically pinned Gen 2 Tapes.
- But conductor/cryostat forces management will be difficult and require novel approaches.