Title
HIGH-FIELD MAGNET DEVELOPMENT ANALYSIS/COIL-TO-RING INTERFERENCE. MAGNET D-5

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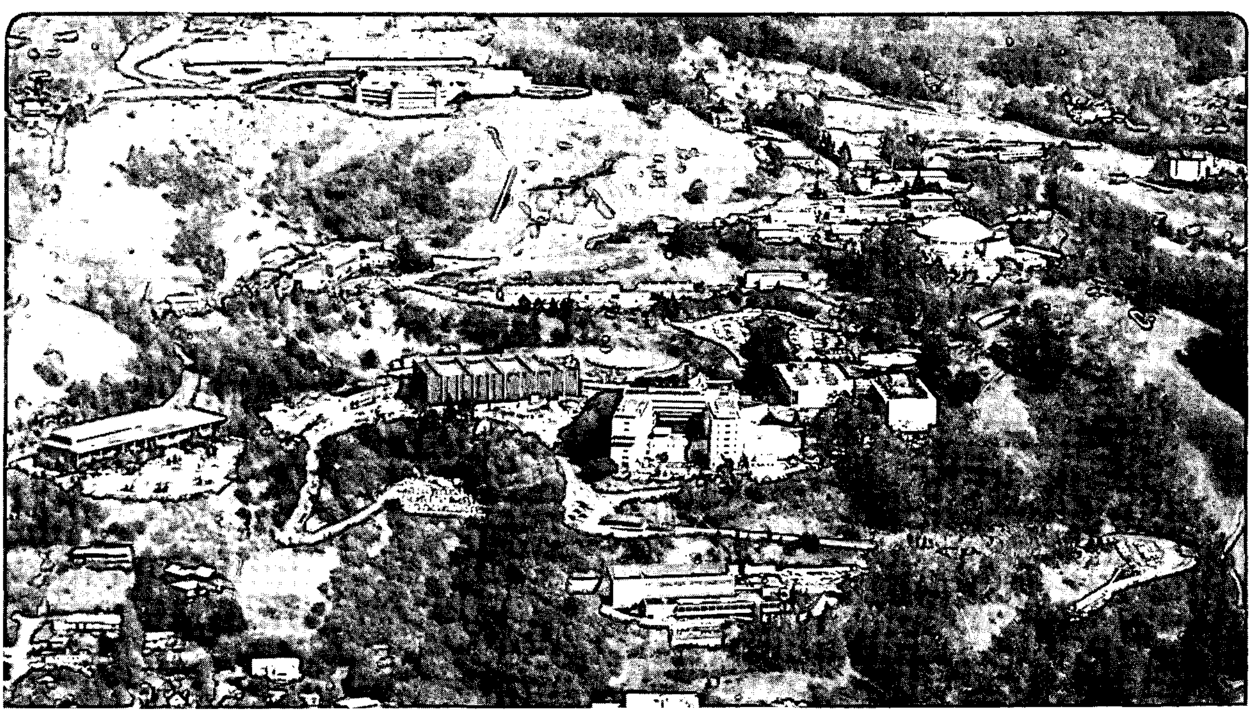

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AUTHOR R. Meuser	DEPARTMENT Mech.	LOCATION Berk.	DATE Oct 29 79	
PROGRAM — PROJECT — JOB High-Field Magnet Development				
Analysis				
TITLE Coil-to-Ring Interference - Magnet D-5				

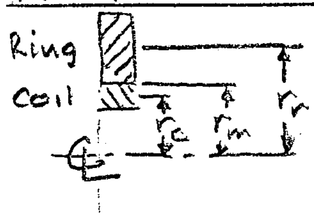
The coil (including the conductor with its insulation, various shims and spacers) is surrounded by the aluminum alloy structural-ring system. The problem is to determine the radial interference between the coil and rings, at room temperature, required to give a specified hoop compressive stress in the coil at 4K.

If the coil were uncompressed and the current applied, there would be a hoop stress at the mid-plane, resulting from the Lorentz forces, of 14000 psi, and zero stress at the poles. To prevent the coil from separating at the poles, a pre-stress of half that is required (Cos-θ winding, Eng. Note M4932, May 1976, Meuser). If we require that there remains a stress of 1000 psi at the poles, giving 15000 psi at the midplane, the required pre-stress is 8000 psi

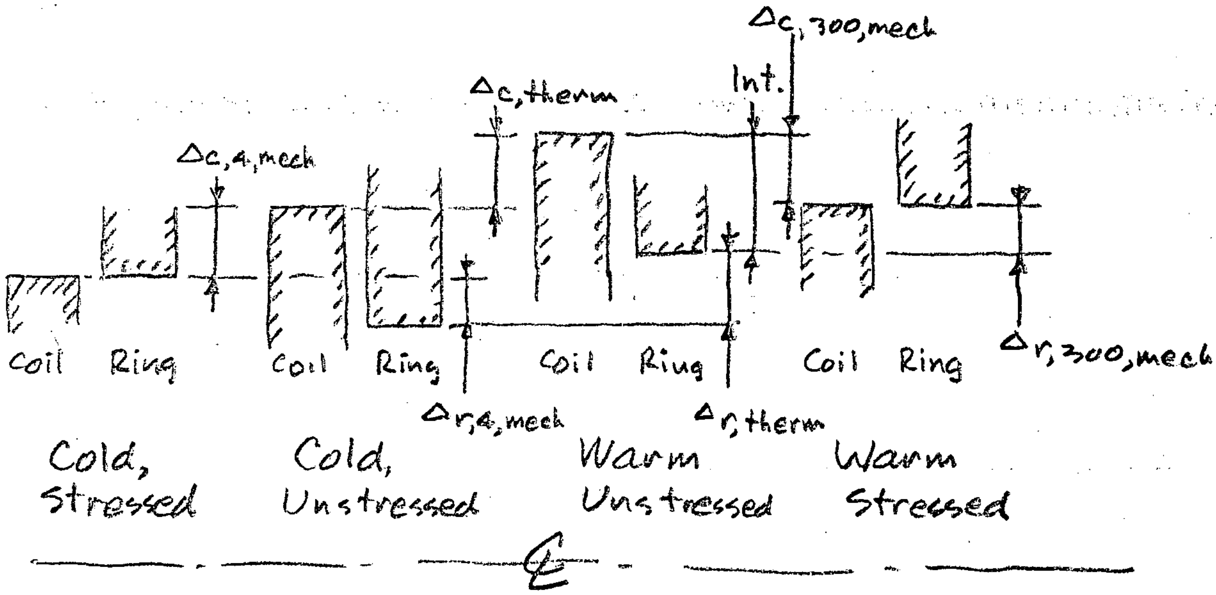
We assume that there is a unique relation between temperature, strain (mechanical plus thermal), and stress, that is, that the coil properties can be described by an equation of state. We have no direct evidence that this is true, or that it isn't. But at present it is all we have to go on.

LAWRENCE BERKELEY LABORATORY - UNIVERSITY OF CALIFORNIA ENGINEERING NOTE		CODE MD1111	SERIAL M5421	PAGE 2 OF 7
AUTHOR Meuser	DEPARTMENT Mech.	LOCATION	DATE Oct 29 79	

NOMENCLATURE



h_c = radial depth of coil
h_r = " " " ring



Δ's are radial displacements.

Sub. "4" = 4K, Sub "300" = 300K
Sub "mech" = mechanical, Sub. "therm" = thermal
Sub "c" = coil, Sub. "r" = structural ring

Signs are such as to be physically positive:

$\Delta_{c,mech}$ is + inward $\Delta_{r\,mech}$ is + outward

$\Delta_{c,therm}$ and $\Delta_{r,therm}$ are + outward upon heating

Hoop stresses are σ_c in coil, σ_r in ring
$+\sigma_c$ is compression, $+\sigma_r$ is tension

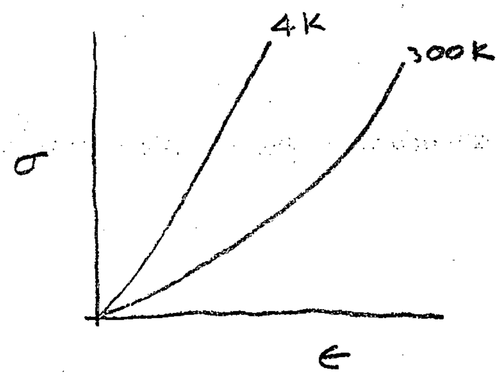
f is the fraction of the circumference occupied by the coil components

f_w is for the conductor + insulation

f_i's are for the i other spacers, islands, etc

$f_w + \sum f_i = 1$

Elastic characteristics of conductor + insulation are represented by stress-strain curves



Elastic properties of everything else (ring, coil spacers) are assumed to be linear: $\sigma = E\epsilon$

Thermal expansion characteristics represented by

$$\Delta l / l = k = \int_4^{300} \alpha \, dT$$

with appropriate subscripts on k.
k is positive for expansion upon heating

PROCEDURE, FORMULAS.

Start with known, assumed, or desired hoop stress in coil; calculate required radial interference at room temp.; calculate room-temp. hoop stresses

Given $\sigma_{c,4}$

Determine corresponding $\epsilon_{w,4}$ from 4K stress-strain curve

$$\Delta_{c,4,mech} = \left[f_w \epsilon_{w,4} + \sigma_{c,4} \sum f_i / E_{i,4} \right] r_c$$

$$\sigma_{r,4} = \sigma_{c,4} \, h_c / h_r$$

$$\Delta_{r,4,mech} = \sigma_{r,4} \, r_r / E_{r,4}$$

AUTHOR	DEPARTMENT	LOCATION	DATE
Meuser	Mech		Oct 29 79

$$\Delta_{c,therm.} = \left[f_w k_w + \sum f_i k_i\right] r_m$$

$$\Delta_{r,therm.} = k_r r_m$$

Required interference at room temperature (see diagram, preceeding page)

$$Int = \Delta_{c,4,mech} + \Delta_{r,4,mech} + \Delta_{c,therm} - \Delta_{r,therm}$$

Calculation of room-temp. stresses requires iteration.

Assume coil stress $\sigma_{c,300}$

Get corresponding strain $\epsilon_{w,300}$ from 300K stress-strain curve

$$\Delta_{c,300,mech} = \left[f_w \epsilon_{w,300} + \sigma_{c,300} \sum f_i / E_{i,300}\right] r_c$$

$$\sigma_{r,300} = \sigma_{c,300} h_c / h_r$$

$$\Delta_{r,300,mech} = \sigma_{r,300} r_r / E_{r,300}$$

$$Int' \equiv \Delta_{c,300,mech} + \Delta_{r,300,mech}$$

If $Int' < Int$, try larger value of $\sigma_{c,300}$

CALCULATIONS

This was programed on the HP 9845 and the results checked against laborious hand calculations.

INPUT DATA

COIL

ITEM	Fraction f	Elast. mod. E_{300}	E_4	Thermal contract. k
Conductor + insul.	.580	—	—	7.5×10^{-3}
Alum. islands	.196	10×10^6	10×10^6	4.0
G-10 island	.167	3.6×10^6	3.6×10^6	2.5
Spacers, Mylar	.005	1×10^6	1×10^6	25.0
Spacers, G-10	.007	2×10^6	2×10^6	5.0
Spacers, Alum.	.045	10×10^6	10×10^6	4.0
	1.000			

Radii: Coil, middle $r_c = 3.685$ in
Coil-to-ring interface $r_m = 4.13$ in
Ring, middle $r_r = 4.93$ in

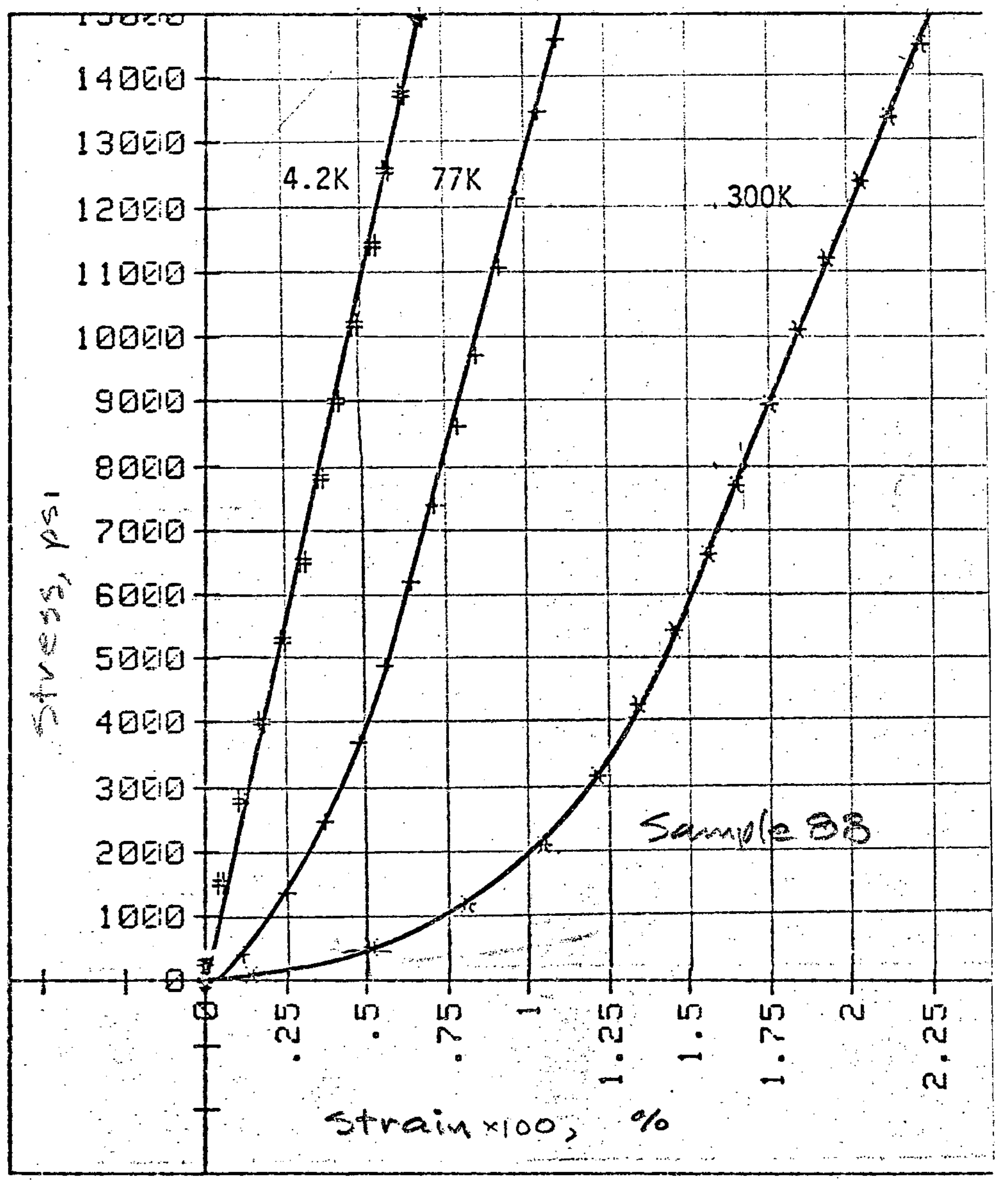
Radial depths: Coil $h_c = 0.8$ in
Ring $h_r = 1.501$ in

Ring modulus: $E_{r,300} = 10\times10^6$ $E_{r,4} = 10\times10^6$

Ring thermal contraction: $k_r = 4.0\times10^{-3}$

Stress-strain curves for conductor + insul.; next page.

LAWRENCE BERKELEY LABORATORY - UNIVERSITY OF CALIFORNIA ENGINEERING NOTE	CODE MD1111	SERIAL M5921	PAGE 6 OF 7
AUTHOR Meuser / DEPARTMENT Mech	LOCATION	DATE Oct 29 79	



Stress-strain curve
From engineering note M5373, Caspi

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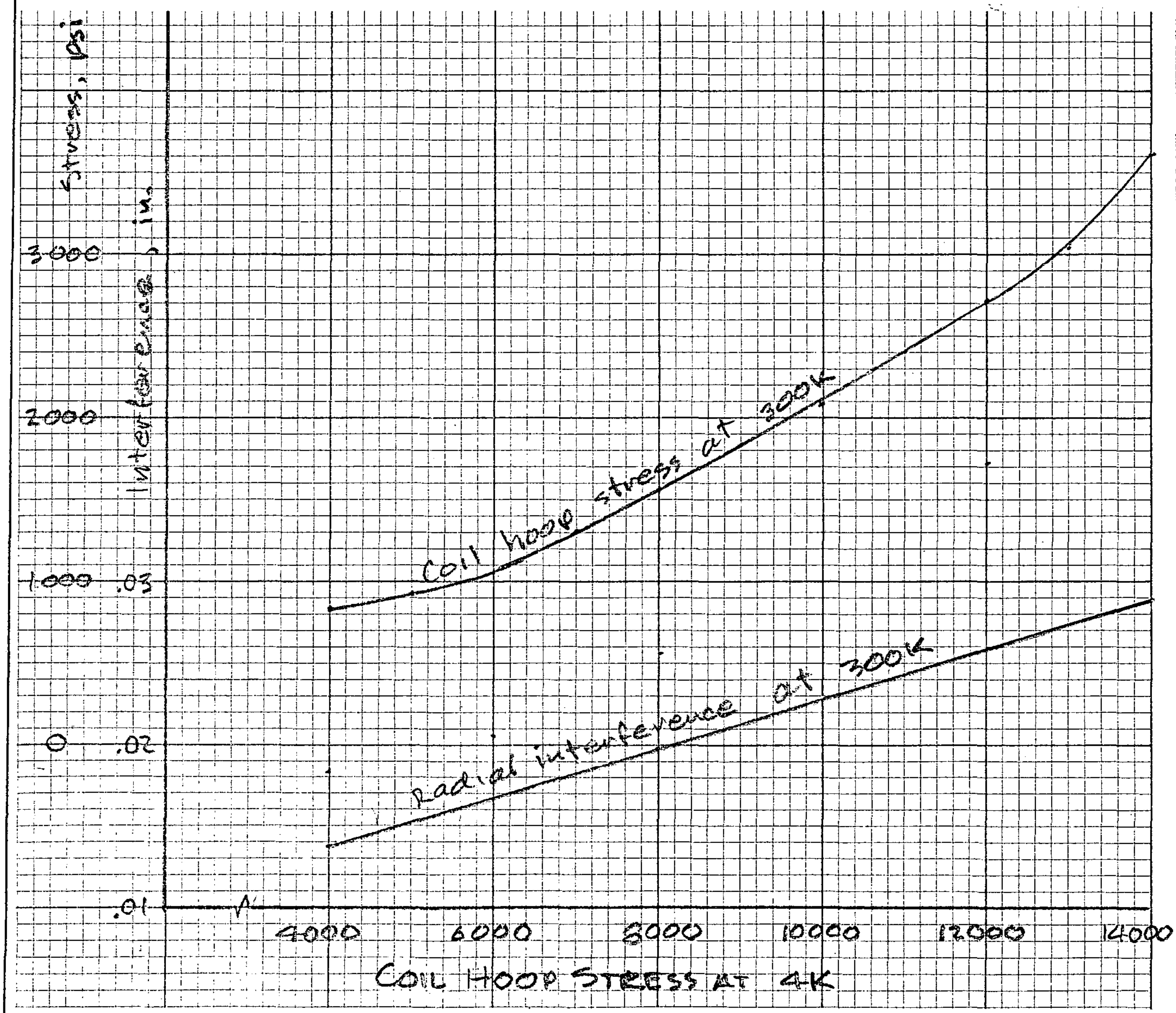
AUTHOR Meuser / DEPARTMENT Mech	LOCATION	DATE Oct 29 79	

RESULTS



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