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## Recent Work

### Title

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

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# Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA, BERKELEY

## Engineering & Technical Services Division

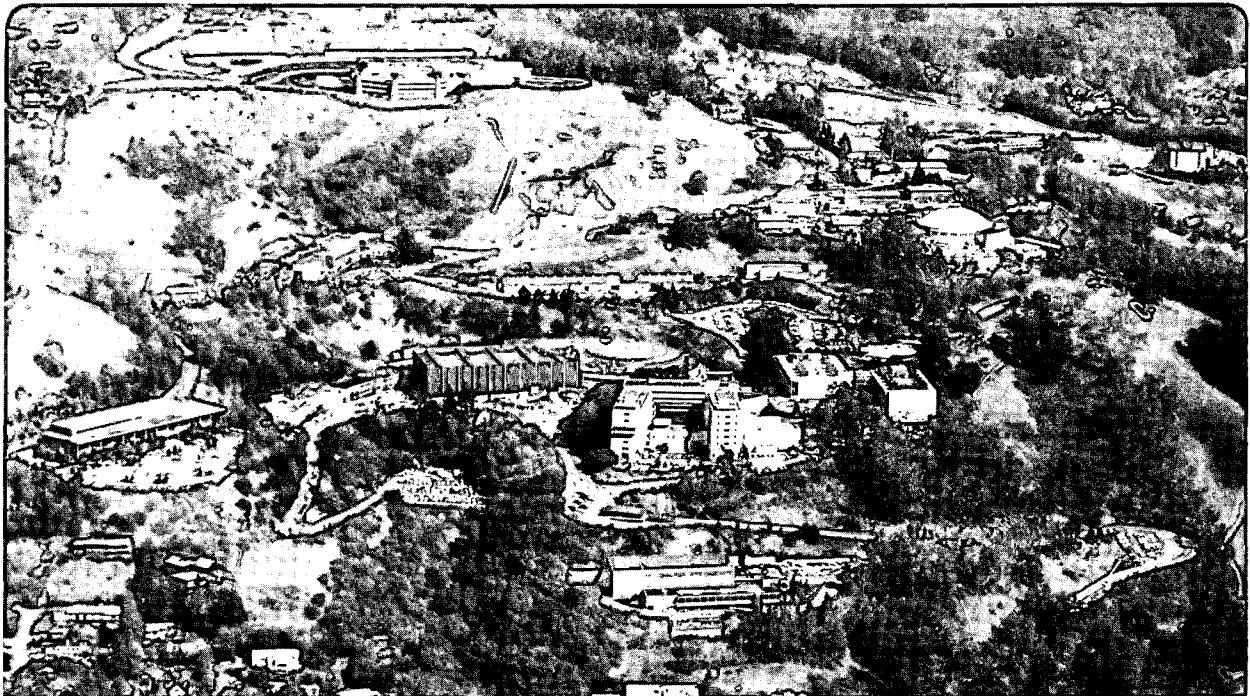
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<b>ENGINEERING NOTE</b>		MD1111	M5421	1 of 7
AUTHOR	DEPARTMENT	LOCATION	DATE	
R. Meuser	Mech.	Berk.	Oct 29 79	
PROGRAM - PROJECT - JOB				
High-Field Magnet Development				
Analysis				
TITLE				
Coil-to-Ring Interference - Magnet D-5				

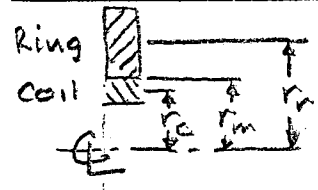
The coil (including the conductor with its insulation, various shims and spacers) is surrounded by the aluminum alloy structural-ring system. The problem is to determine the radial interference between the coil and rings, at room temperature, required to give a specified hoop compressive stress in the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

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- $\theta$  winding, Eng. Note M 4932, 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 8000psi

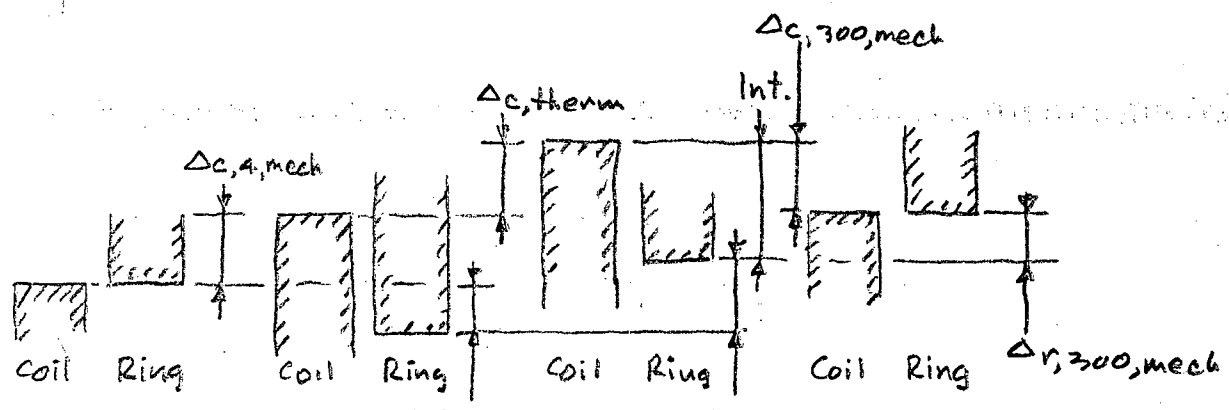
We assume that there is a unique relation between temperature, strain (mechanical plus thermal), and stress, that is, that the coil properties can be described by an equation of state. We have no direct evidence that this is true, or that it isn't. But at present it is all we have to go on.

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NOMENCLATURE



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



Cold, Stressed      Cold, Unstressed      Warm, Unstressed      Warm, Stressed

$\Delta$ '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  $\sigma_c$  in coil,  $\sigma_r$  in ring  
 +  $\sigma_c$  is compression, +  $\sigma_r$  is tension

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

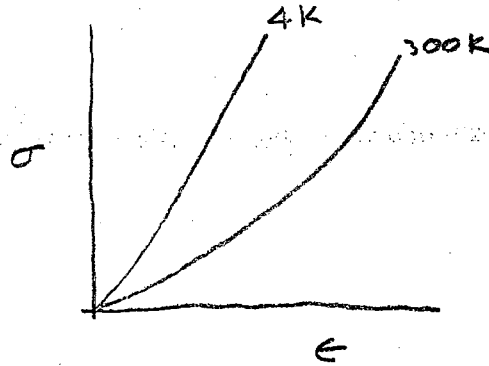
$f_w$  is for the conductor + insulation

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

$$f_w + \sum f_i = 1$$

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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

$$\Delta l/l = k = \int_0^{300} \alpha dT$$

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

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

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

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

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

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

Required interference at room temperature  
(See diagram, preceding page)

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

Calculation of room-temp. stresses requires iteration.

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

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

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

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

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

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

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

### CALCULATIONS

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

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INPUT DATA

COIL

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

Radii: Coil, middle  $r_c = 3.685$  in  
 Coil-to-ring interface  $r_m = 4.13$  in  
 Ring, middle  $r_r = 4.093$  in  
 Radial depths: Coil  $h_c = 0.8$  in  
 Ring  $h_r = 1.501$  in

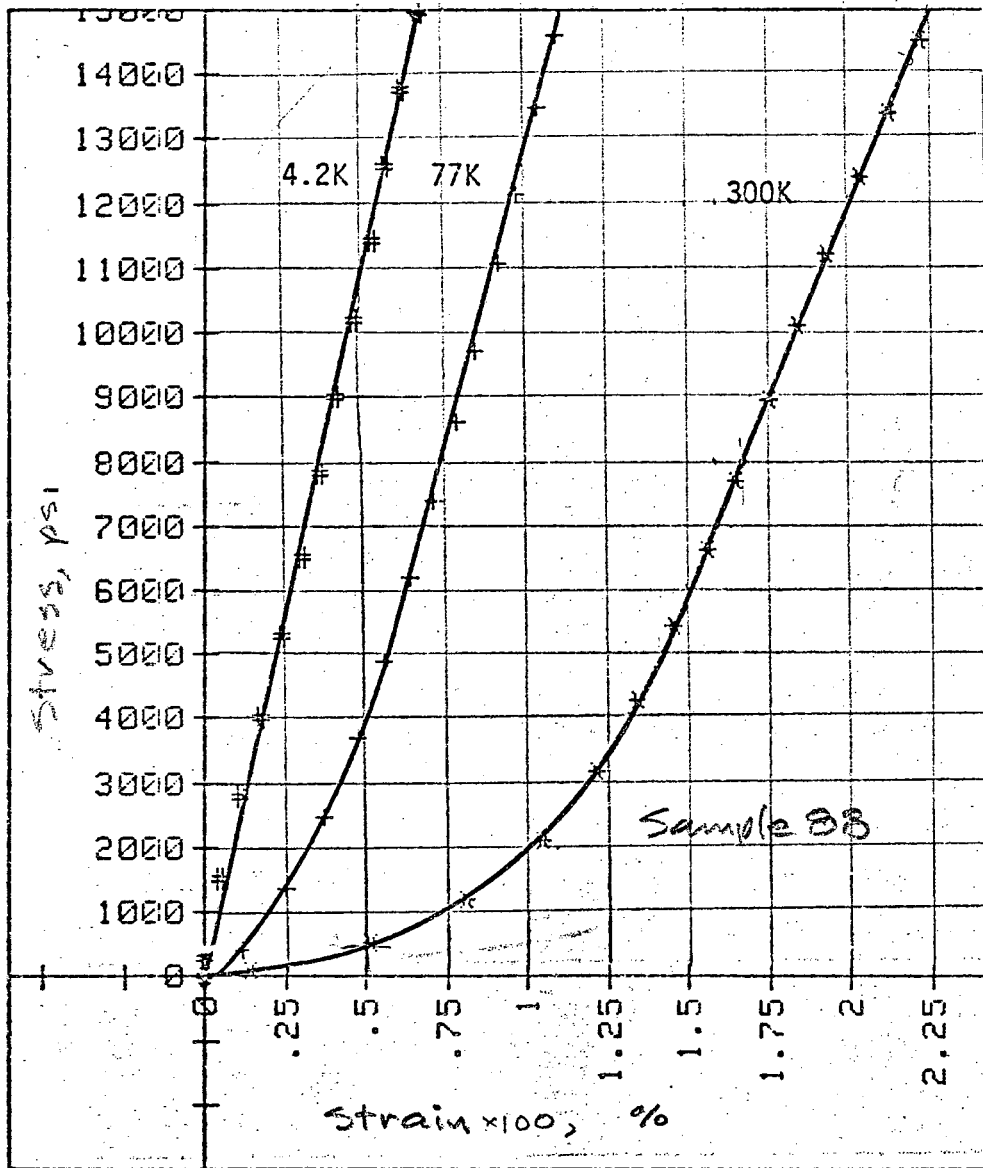
Ring modulus:  $E_{r,300} = 10 \times 10^6$   $E_{r,4} = 10 \times 10^6$

Ring thermal contraction:  $k_r = 4.0 \times 10^{-3}$

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



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Stress-strain curve  
From engineering note M5373, Caspi

# ENGINEERING NOTE

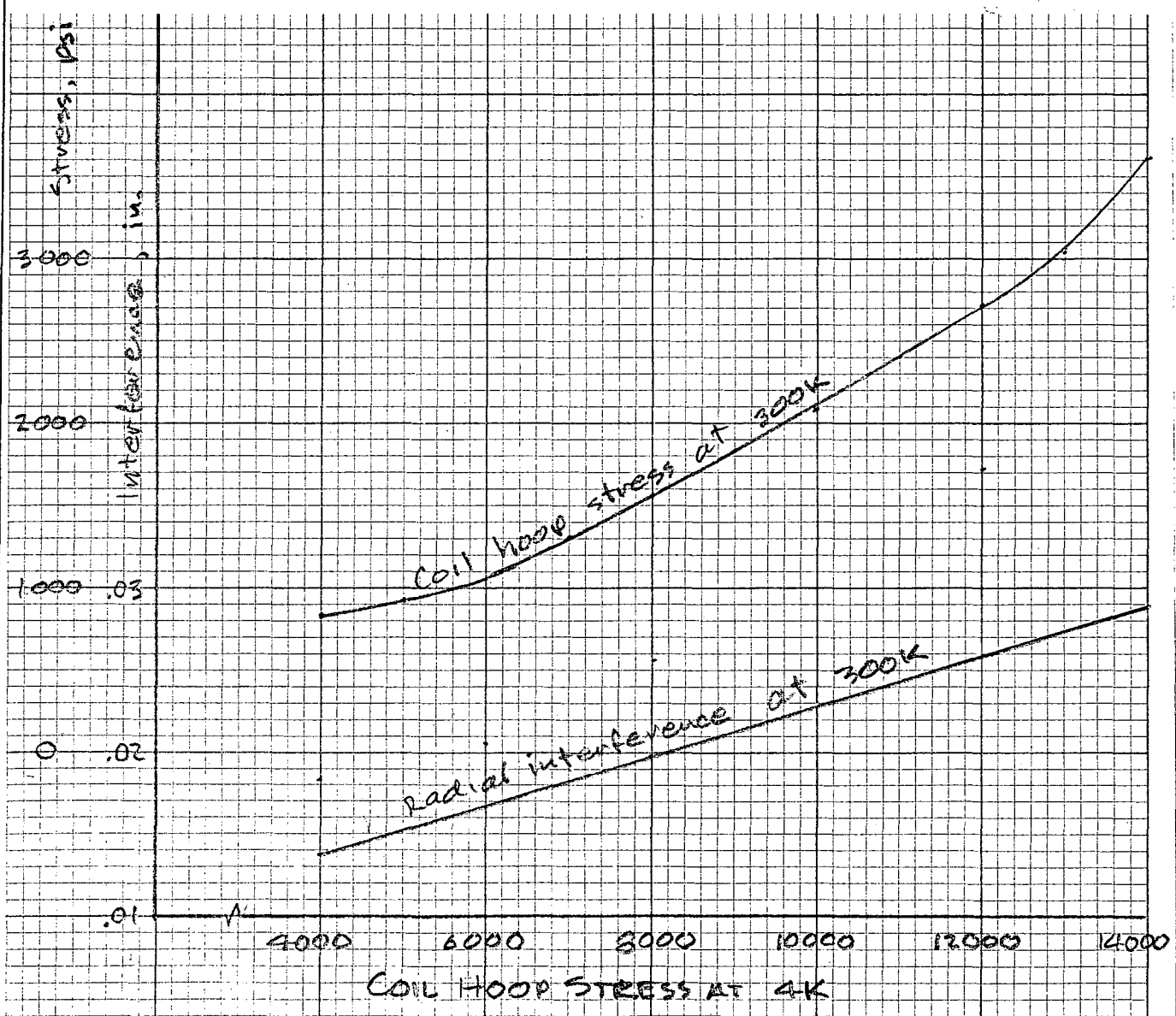
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## RESULTS



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