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## Recent Work

### Title

STIFFNESS OF FNAL-TYPE STRUCTURAL RINGS

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# ENGINEERING NOTE

AUTHOR R. MEUSER

DEPARTMENT MECH. ENG.

LOCATION BERK

DATE 8-19-81

PROGRAM - PROJECT - JOB  
HIGH-FIELD MAGNET DEVELOPMENT  
ANALYSIS

TITLE  
STIFFNESS OF FNAL-TYPE STRUCTURAL RINGS

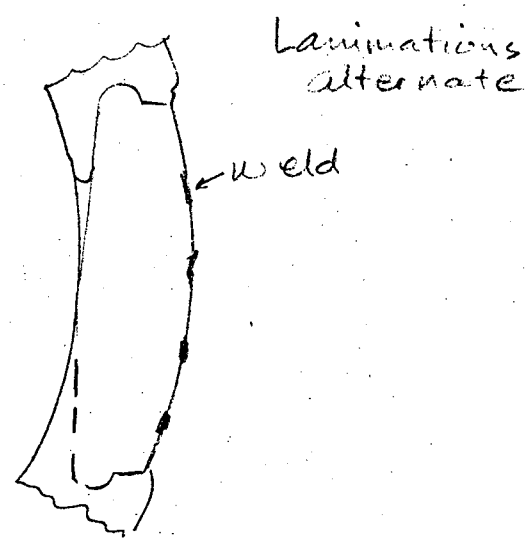
Inasmuch as we are planning to use FNAL type structural rings for our warm-iron alternative ISAbelle dipole magnet, it seems prudent to find out how stiff their weird joints are, as that effects both the stiffness and stresses in the rings.

We took a 1-inch stack of rings, cut away one side, applied a load as shown, and measured the deflections A and B.

From these measurements, we infer that the joint is 0.26 to 0.35 times as stiff as solid metal. I wouldn't have guessed it to be that low, so I am somewhat sceptical of the results.

Thanks to Al Borden for setting things up and running the test.

## Joint



~Full size

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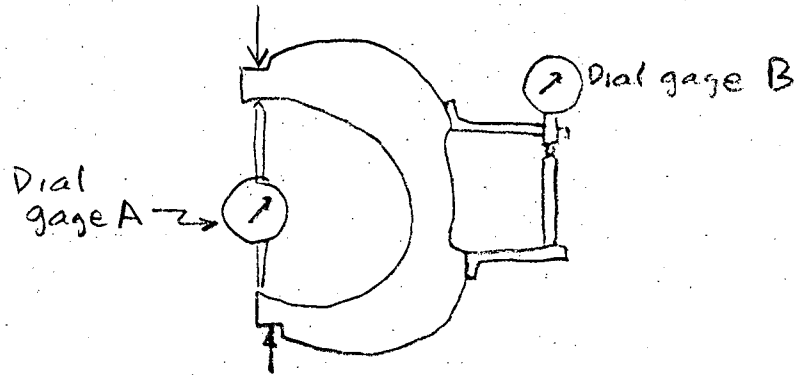
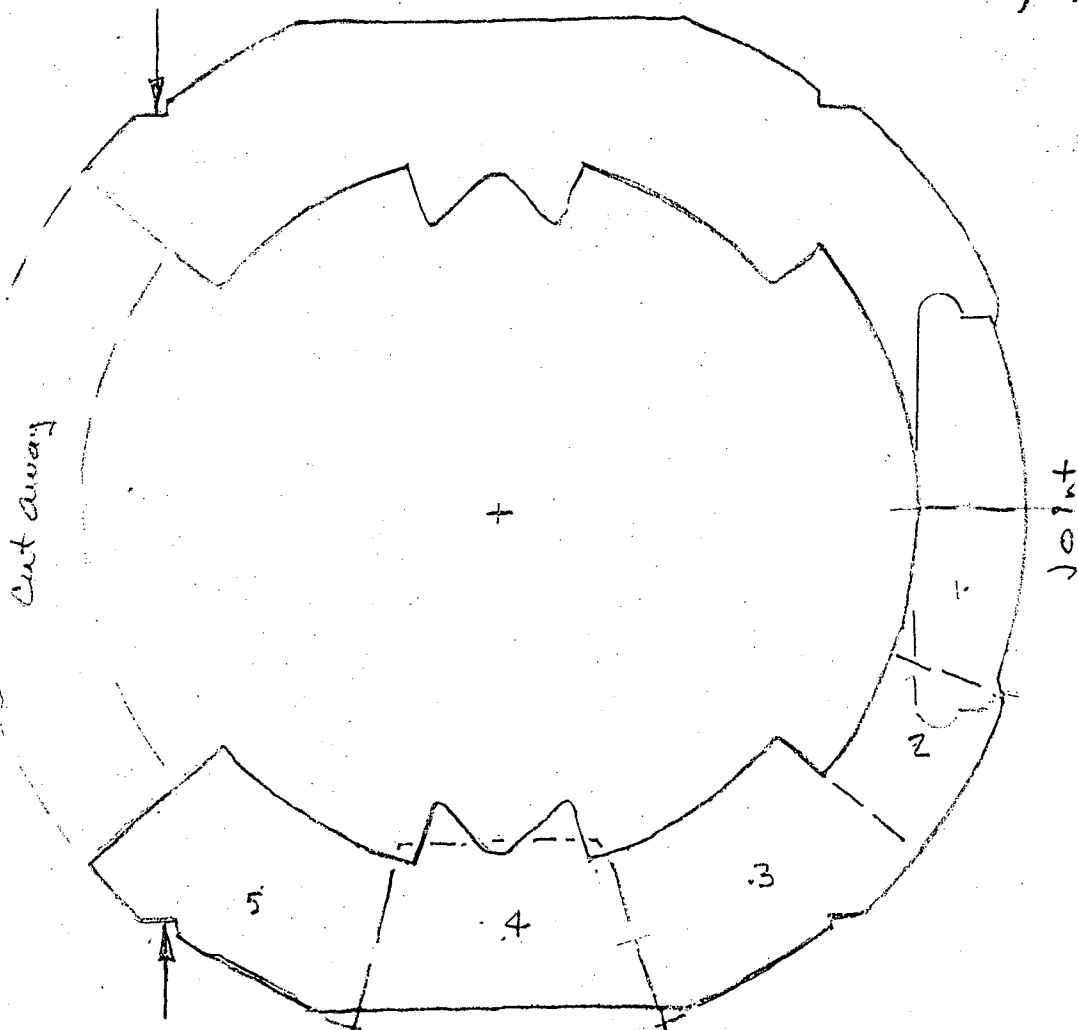
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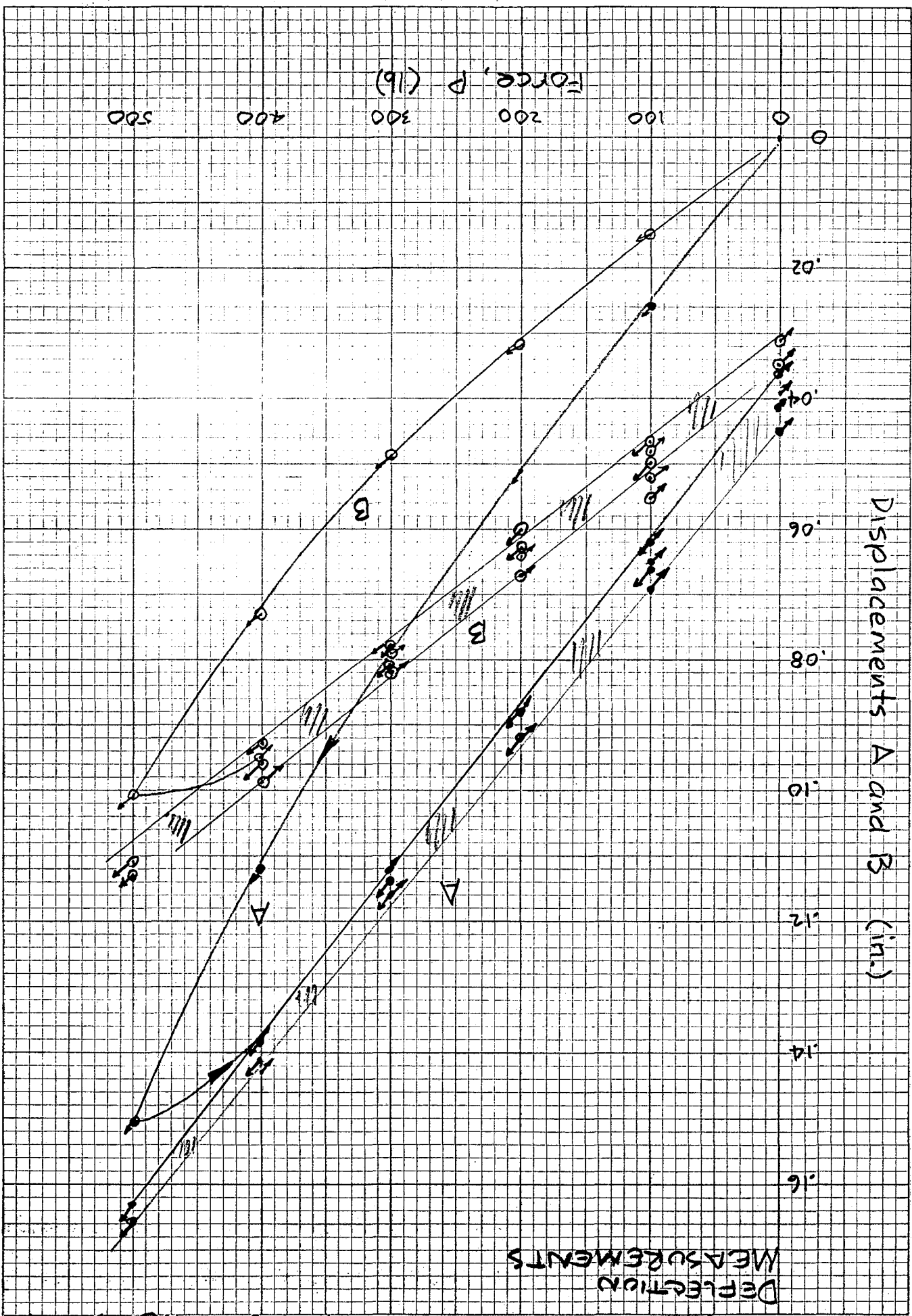
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Set-UpRing Cross Section showing elements used for analysis



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DEFLECTION MEASUREMENTS

Displacements A and B (in.)

Force, P (lb)

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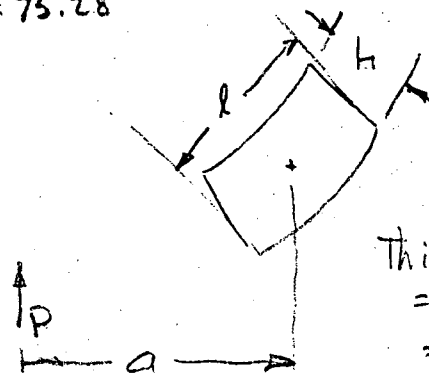
Dimensional Data

Element No	Dist from load, a	Length l	Thickness h	$\frac{a^2 l}{h^3}$	$\frac{l}{h}$
1	4.18	0.86	.572	80.29	1.50
2	3.91	0.83	.632	50.27	1.31
3	3.06	1.33	.885	17.97	1.50
4	1.76	1.30	.850	6.56	1.53
5	0.50	1.33	.885	.48	1.50

$$\sum_{i=1,2} l/h = 2.81$$

$$\sum_{i=3,5} l/h = 4.53$$

$$\sum_{i=2,5} a^2 l / h^3 = 75.28$$



$$\begin{aligned} \text{Thickness} &= b \\ &= 16 \times .061 \\ &= 0.976 \end{aligned}$$

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## Joint Efficiency Inferred From Deflection A

We use the deflection  $A$  as a measure of the angular rotation of the joint. But not all of the deflection is a result of the joint rotation; part of it results from shear and extension\* of all parts of the ring, and from bending of parts other than the joint. So we correct for these other deflections

Displacement  $A$  resulting from extensions\*

This is primarily due to the extension\* of elements 1 and 2:

$$A = 2 \sum_{i=1,2} \frac{Pl}{bhE} = \frac{2P}{bE} \sum_{i=1,2} \frac{l}{h} = \frac{2P}{bE} \times 2.81 = 5.62 \frac{P}{bE}$$

Displacement  $A$  resulting from shears

This is primarily due to the shear displacements of elements 3, 4, and 5:

$$A = 2 \sum_{i=3,5} \frac{Pl}{bhG} = 2 \frac{P}{bG} \sum_{i=3,5} \frac{l}{h}$$

$$G = \frac{E}{2(1+\nu)} = \frac{E}{2(1+.3)} = \frac{E}{2.6}, \text{ so}$$

$$A = 2 \times 2.6 \frac{P}{bE} \sum_{i=3,5} \frac{l}{h} = 2 \times 2.6 \frac{P}{bE} \times 4.53 = 23.6 \frac{P}{bE}$$

Displacement  $A$  resulting from rotations.

$$A = 2 \sum \left( \frac{Ml}{EI} \right) a, \quad I = \frac{bh^3}{12}, \quad M = Pa$$

$$A = 24 \frac{P}{Eb} \sum_{i=2,5} \frac{la^2}{h^3} = 24 \frac{P}{Eb} \times 75.28 = 1806 \frac{P}{bE}$$



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The total of these gives

$$\begin{aligned} A/P &= \frac{5.62 + 23.6 + 1806}{bE} \\ &= \frac{1836}{.976 \times 30 \times 10^6} = 62.7 \times 10^{-6} \text{ in/lb} \end{aligned}$$

The measured value is

$$A/P = 250 \times 10^{-6}$$

so the part resulting from joint rotation is

$$\begin{aligned} \underbrace{(A/P)}_{\text{measured}} &= (250 - 62.7) \times 10^{-6} = 187 \times 10^{-6} \text{ in/lb} \end{aligned}$$

For a solid joint, the deflection  $A$  is

$$A = 2 \left( \frac{Ml}{EI} a \right), \quad M = Pa, \quad I = \frac{bh^3}{12}, \quad \text{so}$$

$$\begin{aligned} \underbrace{(A/P)}_{\text{"theoretical"}} &= 24 \frac{1}{Eb} \left( \frac{Pa^2}{h^3} \right) \\ &= \frac{24}{30 \times 10^6 \times .976} 80.29 = 65.81 \text{ in/lb} \end{aligned}$$

Define  $K = \frac{\text{stiffness, } P/A, \text{ of actual joint}}{\text{solid}}$

$$= \frac{(A/P)_t}{(A/P)_m} = \frac{65.81 \times 10^{-6}}{187 \times 10^{-6}} = \underline{\underline{0.35}}$$

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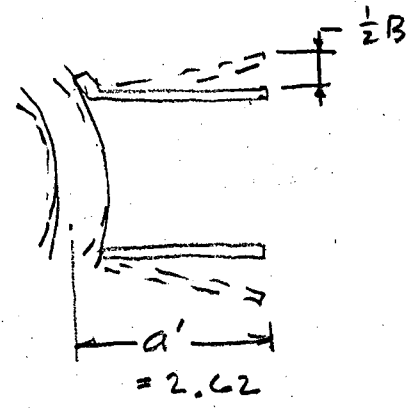
Joint Efficiency Inferred From Deflection B

Measured displacement/load,  $B/P = 160 \times 10^{-6}$  in/lb  
 Disp./load due to element extension (see previous calculation)

$$B/P = \frac{5.62}{bE} = \frac{5.62}{.976 \times 30 \times 10^6} = 0.2 \times 10^{-6}, \text{ ignore.}$$

For a solid joint, the displacement B is

$$B/P = \frac{24}{Eb} \left( \frac{laa'}{h^3} \right) \text{ (see previous calcs)}$$



$$= \frac{24}{30 \times 10^6 \times .976} \times \frac{.86 \times 4.18 \times 2.62}{.572^3} = 41.25 \times 10^{-6} \text{ in/lb}$$

The joint efficiency, then, is

$$K = \frac{41.25 \times 10^{-6}}{160 \times 10^{-6}} = \underline{\underline{0.26}}$$

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