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Approximate Stress versus Strain Relations for Collar Gages

In general, the relation between coil stress and the strain measured with the beam gages used in the SSC magnet collars is provided by a cubic equation. This equation is derived by fitting to data obtained in a calibration fixture where the strain is measured for a series of stresses applied to the beam gage through a cable "ten stack" which is supposed to mimic the response of a coil. However several SSC magnets (both long and short) were instrumented with collar gages that, for a variety of reasons, were badly calibrated. It is possible to recover some of the information from these gages by approximating the cubic expression with a linear equation over most of the active range of the gage. This note discusses the linear approximation and the errors associated with its use.

We obtain the best linear equation by fitting to calibration curves obtained at Brookhaven National Laboratory (BNL) for two sets of gages, one set (8 gages) built at BNL and one set (7 gages) built at Fermilab (FNL). We assume that errors associated with the cubic fit to the calibration data are neglibible relative to the following analysis. Figure 1 shows the calibration curves for the BNL gages. These are curves obtained by fits to data obtained with the BNL calibration fixture at room temperature and at approximately 4°K. Figure 2 shows the calibration curves for the gages built at FNL. (Note that there seems to be better uniformity across gages built at BNL.) We obtain our linear fit by calculating the stress from each curve for strains between 200 and 2500 µstrain at 100 µstrain intervals and then fitting to these data points. The results of these fits are also shown in the figures. There is close agreement between the BNL and FNL built gages at both temperatures. The linear equation we obtain using this analysis which approximates the stress to strain relationship at room temperature is:

$$\text{Stress} = (-1400 + 8.6 \times \mu e)\ \text{lbs/in}^2.$$

At 4.2°K the equation becomes:

$$\text{Stress} = (-2000 + 11.3 \times \mu e)\ \text{lbs/in}^2.$$

To obtain a crude estimate of the errors associated with this approximation, we take the warm FNL data at midrange (1500 μe) and calculate the standard deviation of the distribution. This is 1300 lbs/in^2. (At midrange, the warm FNL data has the largest spread and so will give us the most conservative error estimate. This may still be an underestimate of the error at the upper end of the range for the FNL gages when at 4.2°K, however the gages usually do not see stresses this high at cold temperatures.) We then note that the linear equation systematically overestimates the stress near 700 μe in the 4.2°K data and underestimates the stress in the very low part of the range at room temperature. This systematic error is (conservatively) 700 lbs/in^2. Table 1 shows the data from the 7 gages from which these errors were derived.

There are at least two additional sources of systematic error for which we do not have a good estimate. The first derives from the assumption that the calibration technique using "ten stacks" properly simulates the interaction between the gage block and the coil. There is some indication that variations in the unstressed coil modulus affects the behavior of the stress to strain curve in the low strain range. This would have two effects on the above analysis. It would change the offset term and the lower bound of the acceptable range. The second source of systematic error arises with the placement of the gage block in the collar pack. Care must be excersized in adjusting the height of the gage block to match the height of the surrounding collar laminations to insure that the coil is experiencing the same stress at the gage as elsewhere in the collar. Systematic errors on the order of 1000 lbs/in^2 per mil of misalignment are theoretically possible.

In summary, the linear approximation which can be used to obtain coil stress from uncalibrated collar gages over the range [200 μstrain, 2500 μstrain] is:

$$\textbf{Stress} = (-1400 + 8.6 \times \mu e) \pm 1300(\text{stat}) \pm 700(\text{sys}) \ \ \text{lbs/in}^2$$

at 300 °K,

$$\textbf{Stress} = (-2000 + 11.3 \times \mu e) \pm 1300(\text{stat}) \pm 700(\text{sys}) \ \ \text{lb/in}^2$$

at 4.2°K,

with the caveat that the user must add his/her best estimate of the systematic error due to gage placement and calibration technique.

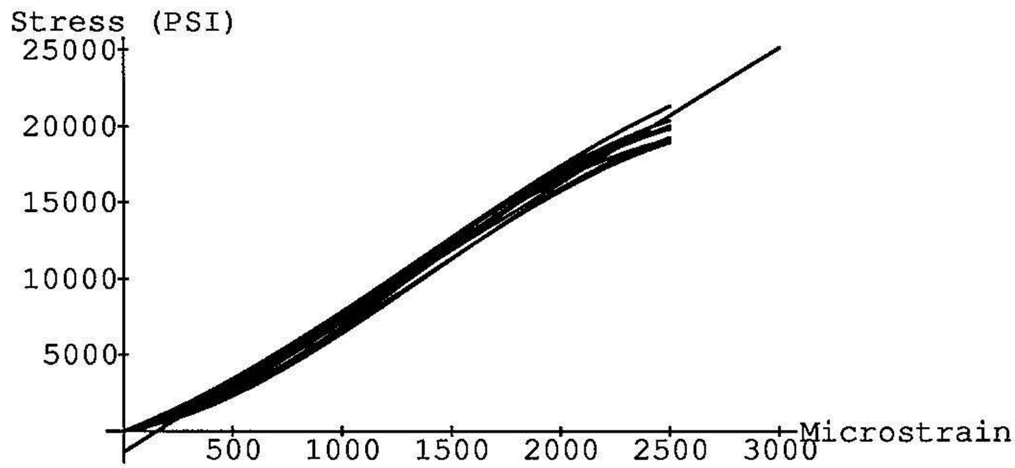

Fig. 1

BNL gages calibrated at BNL at about 300K. The line shown is the best linear fit to these curves over the range of 200 to 2500 microstrain. It has the form -1365+8.82x.

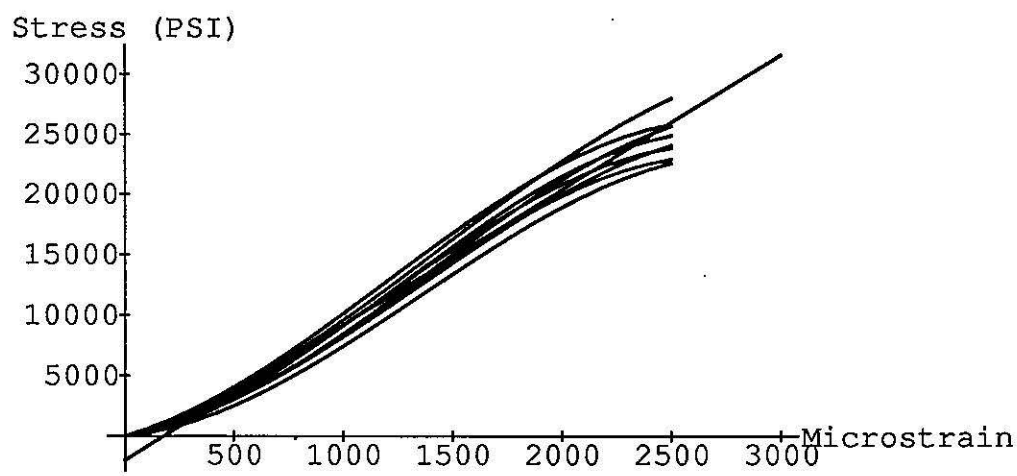

Fig. 2

BNL gages calibrated at BNL at about 4.2K. The line shown is the best linear fit to these curves over the range of 200 to 2500 microstrain. It has the form -2017+11.2x.

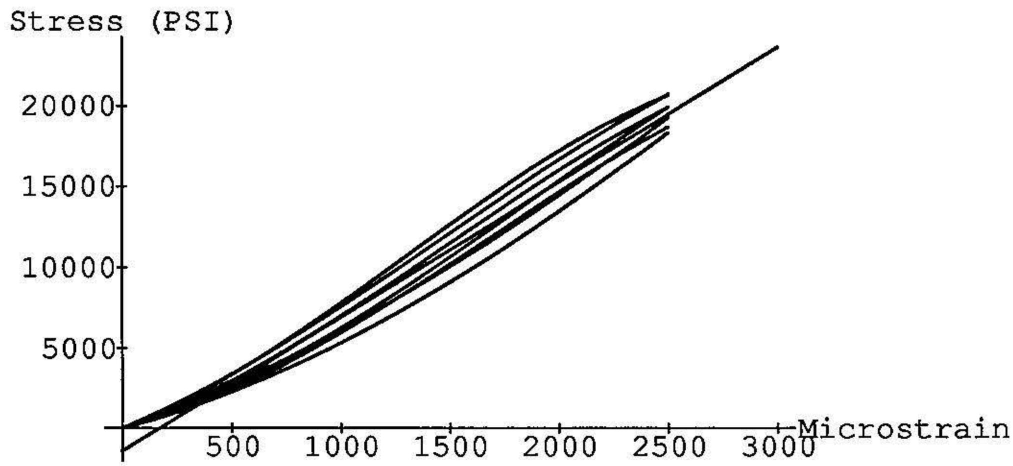

Fig. 3

FNL gages calibrated at BNL at about 300K. The line shown is the best linear fit to these curves over the range of 200 to 2500 microstrain. It has the form -1417+8.35x.

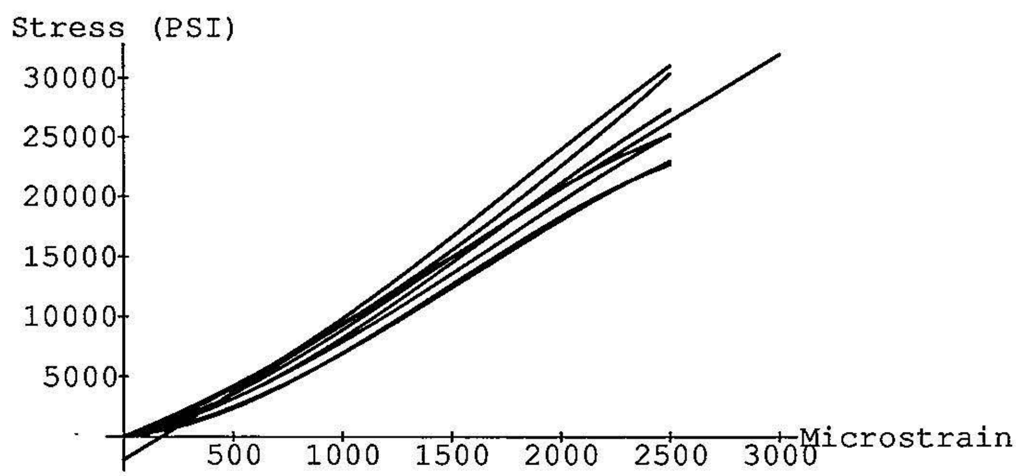

Fig. 4

FNL gages calibrated at BNL at about 4.2K. The line shown is the best linear fit to these curves over the range of 200 to 2500 microstrain. It has the form -1949+11.31x.

Strss vs. Strain Analysis

	A	B	C	D
1	FNL stress at 1500 με (room temp)	FNL stress at 1500 με (4.2°K)	FNL stress at 700 με (4.2°K)	FNL stress at 200 με (room temp)
2	12676	16262	5964	1169
3	10246	14270	4872	767
4	9120	15697	5428	800
5	10075	14495	5008	1027
6	12151	16791	6312	1240
7	10673	15434	5618	877
8	11537	15010	4986	1053
9	Average	Average	Average	Average
10	10925.42857	15422.71429	5455.428571	990.4285714
11	Standard Deviation	Standard Deviation	Standard Deviation	Standard Deviation
12	1254.903032	913.9386767	544.7454626	181.8771171
13			Calculated value	
14			5910	320
15			Systematic offset of calcula	Systematic offset of calculated
16			value from average:	value from average:
17			-454.5714286	670.4285714

Table 1

Distribution:

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- M. Lamm
- J. Strait
- M. Wake
- M. Winters