Fermi National Accelerator Laboratory

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Investigation of Factors Affecting the Calibration of Strain Gage Based Transducers ('Goodzeit Gages') for SSC Magnets*

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INVESTIGATION OF FACTORS AFFECTING THE CALIBRATION OF STRAIN GAGE BASED TRANSDUCERS ('GOODZEIT GAGES') FOR SSC MAGNETS

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ABSTRACT

These transducers are designed to measure stresses on SSC collared coils. They are individually calibrated with a bonded ten-stack of SSC inner coil cable by applying a known load and reading corresponding output from the gages. The transducer is supported by a notched 'backing plate' that allows for bending of the gage beam during calibration or in use with an actual coil. Several factors affecting the calibration and use of the transducers are: the number of times a 'backing plate' is used, the similarities or differences between bonded ten-stacks, and the differences between the ten-stacks and the coil they represent. The latter is probably the most important because a calibration curve is a model of how a transducer should react within a coil. If the model is wrong, the calibration curve is wrong.

Information will be presented regarding differences in calibrations between Brookhaven National Labs (also calibrating these transducers) and Fermilab - what caused these differences, the investigation into the differences between coils and ten-stacks, and how they relate to transducer calibration, and some suggestions for future calibrations.

INTRODUCTION

A brief description of how and why calibrations are done provides some background. The calibrations of beam transducers began at Fermilab in late 1989. Initially there were large differences in calibration data between Fermilab and Brookhaven. These differences persisted until our calibration system came fully on line during the summer of 1990. Basically, the two calibration setups are the same equipment. They consist of a loading press (manually controlled at Fermilab), a load cell to read loading forces, an HP3457A multimeter to read load cell and strain gage input/output, and a PC to control the meters and convert the gage output into microstrain. Transducers are calibrated two at a time by mounting them at the top and bottom of a ten-stack of SSC inner coil cable. A known load is transmitted to the beam. The beam is allowed to bend because of the presence of a notched 'backing plate' that supports only the ends of the beam. The gage is mounted to the beam and stretches and changes resistance to correspond with the applied load.[1] The transducers are calibrated up to a load of 18,000 psi. Data is collected continuously during the loading cycle at Fermilab. BNL collects data at ten discrete points along the loading curve. After the data is collected, the resistance measurements are converted to microstrain. A cubic equation is fitted to the microstrain versus coil psi data. After the calibration, the transducers are installed into notched collar sections of a

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magnet. They are used to measure pre-stress during collaring and later during the actual tests of the magnets. The calibration curves at the two Labs initially varied markedly as far as the gage output was concerned. See Figure 1 and 2. The gages calibrated at BNL had far less output than the ones at Fermilab. The following is an investigation into what caused these differences and how they were overcome.

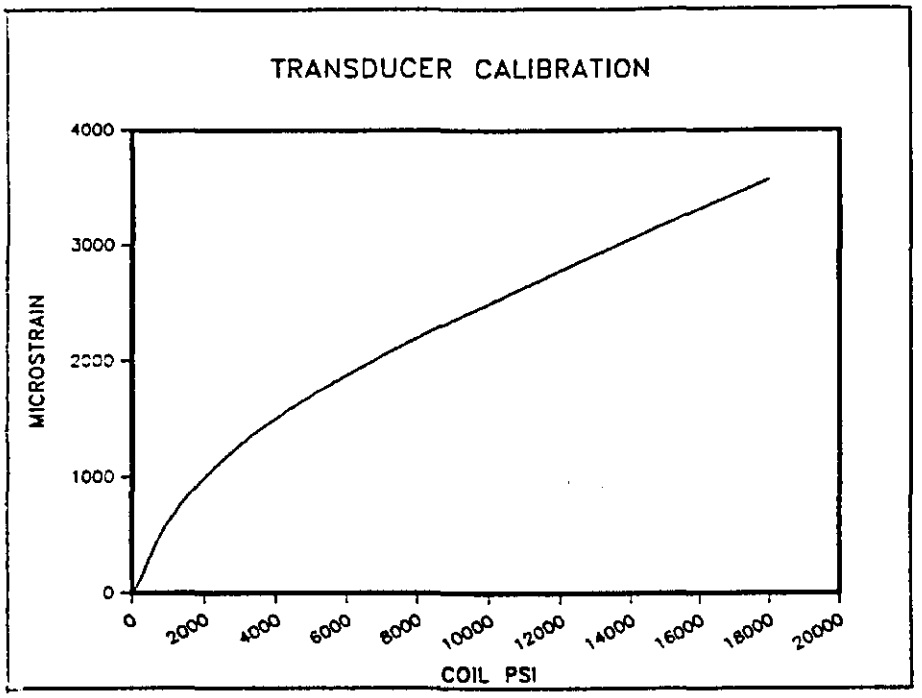

Fig. 1 Initial calibration done at Fermilab.

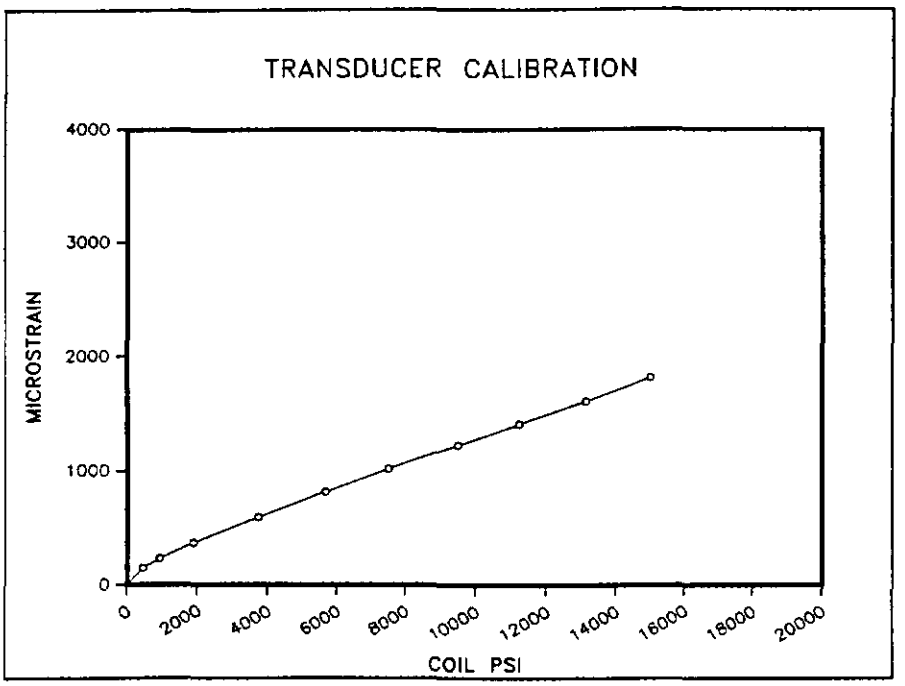

Fig. 2 Calibration of a transducer done at BNL.

INVESTIGATION

Major Differences in Calibrations

Initially, the backing plate was reused for every calibration. The backing plates were inspected and found to be bowed by approximately 0.0025" in the loading direction. This was causing the beam to load unevenly resulting in inaccurate calibrations. This can be seen in the calibration curve in Figure 3, where the calibration was done with an overused backing plate. It can be seen that when the plate was replaced, the curve became much steeper and corresponded with other calibrations. See Figure 4. As a result, new backing plates were used for each calibration.

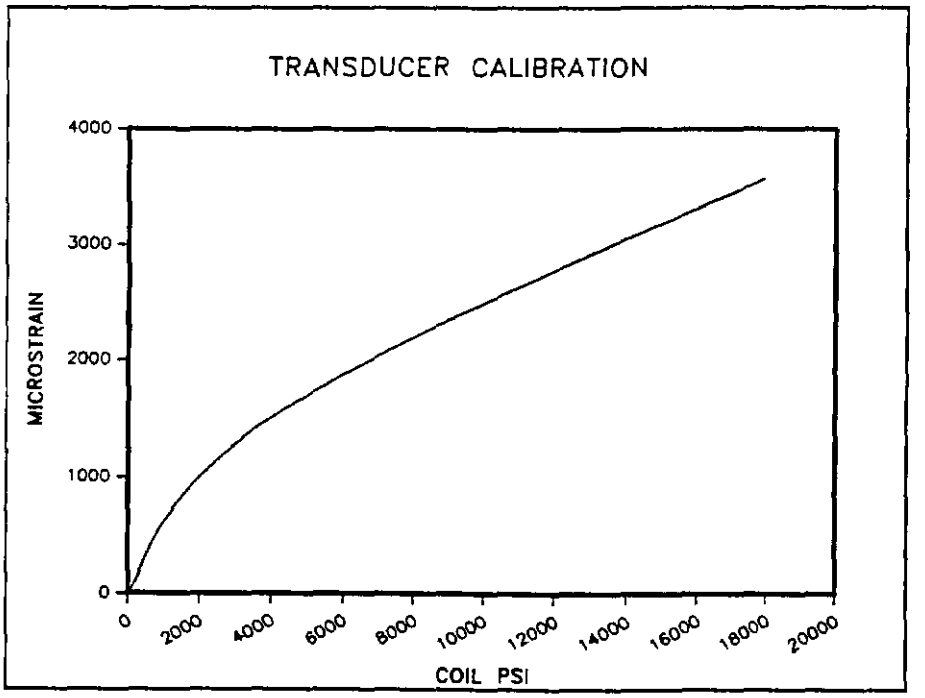

Fig. 3 Calibration of a transducer with a bent backing plate.

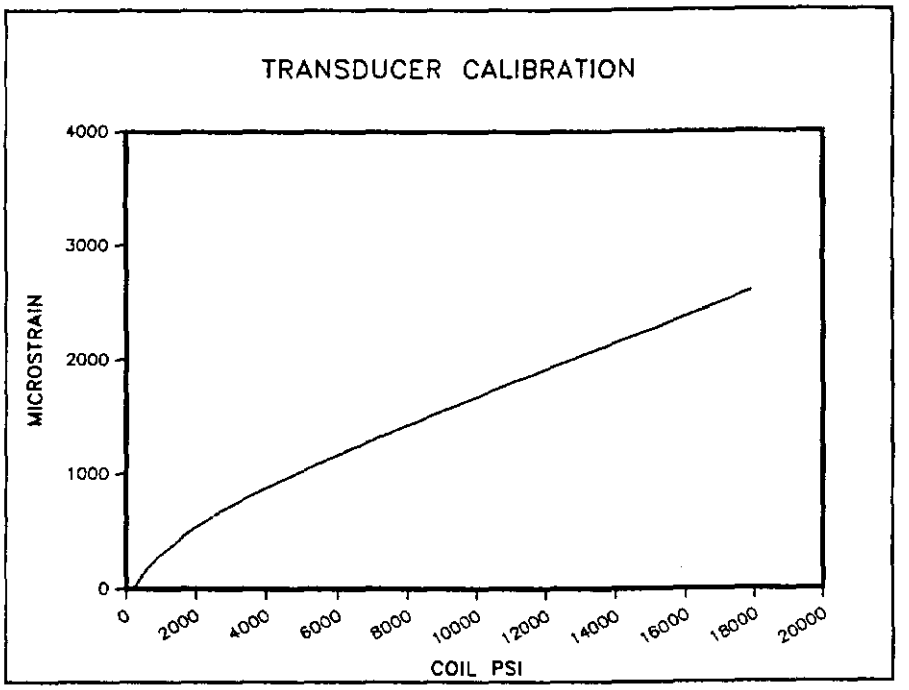

Fig. 4 Calibration of transducer done with new backing plate.

During the initial calibrations of the beams, several variations on the calibration setup were used. The ten-stacks were initially cut to the length of the calibration fixture. When a ten-stack comes out of the fabrication press, it is approximately 4" in length. The thought was then to cut the ten-stack down to the length of the fixture, 1.5", so the stack would fit with little clearance. See Figure 5. The length of the ten-stack itself did not contribute to inaccurate calibrations. The damage during the cutting process caused the calibration curves to vary. Compare Figure 6 and 7. It is of interest to note that coils made at Fermilab have some of these same qualities. They are not an example of poor coils or ten-stacks, but are a reflections of the epoxy content of the fiberglass tape used to wrap the coil. The comparison can be made between cutting a BNL ten-stack and a Fermilab ten-stack. The calibration curves indicate that the transducer calibrated with a cut BNL ten-stack and an uncut BNL ten-stack are relatively the same. See Figure 8. This is due to the compact nature of BNL's ten-stack. The cutting had very little effect on the bonds between cables. The more loosely bonded was the ten-stack, the more susceptible it was to damage during calibrations. Their reuse led to further damage of the bonds between cables. This caused the stack to become looser and calibrations worse as the condition of the stack deteriorated. See Figure 9. New ten-stacks are now used to calibrate against two gages for each calibration, and the stacks are kept at their original fabrication length.

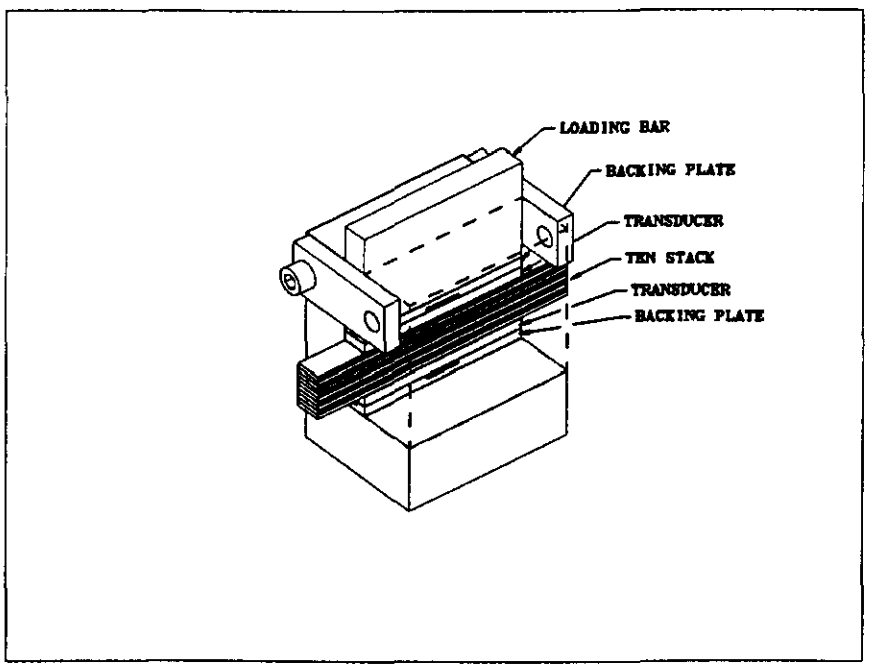

Fig. 5 Calibration fixture and set-up.

Investigation of Ten-Stacks

The major difference between calibrations is currently the ten-stack. Ten-stacks fabricated at BNL are very compact and have an appearance of a solid block. The cables are wrapped in an epoxy tape with an epoxy content of 23%. The ten-stack is heated during bonding to cure the epoxy, and the stacks are approximately 0.639."

The ten-stacks fabricated at Fermilab are not bonded together as tightly as BNL's, and are approximately 0.650" tall. Fermilab's tape has an epoxy content of about 18%. Upon examination of the two ten-stacks stress/strain curves, the BNL curve has a much lower change in percentage strain per coil psi than the Fermilab stack. Load deflection measurements were taken of an actual coil during coil sizing. The elastic modulus was calculated from this and compared to ten-stacks made by BNL and Fermilab. See Table 1. The elastic modulus of the BNL stack is slightly higher than the Fermilab stack. The measured coil modulus during sizing was higher for this particular coil. It is apparent that the modulus has a direct relationship to gage output. The greater the modulus, the

lower the gage output. Compare a BNL calibration to that of a Fermilab calibration. See Figures 2 and 10. There are, however, other coil characteristics that merit attention.

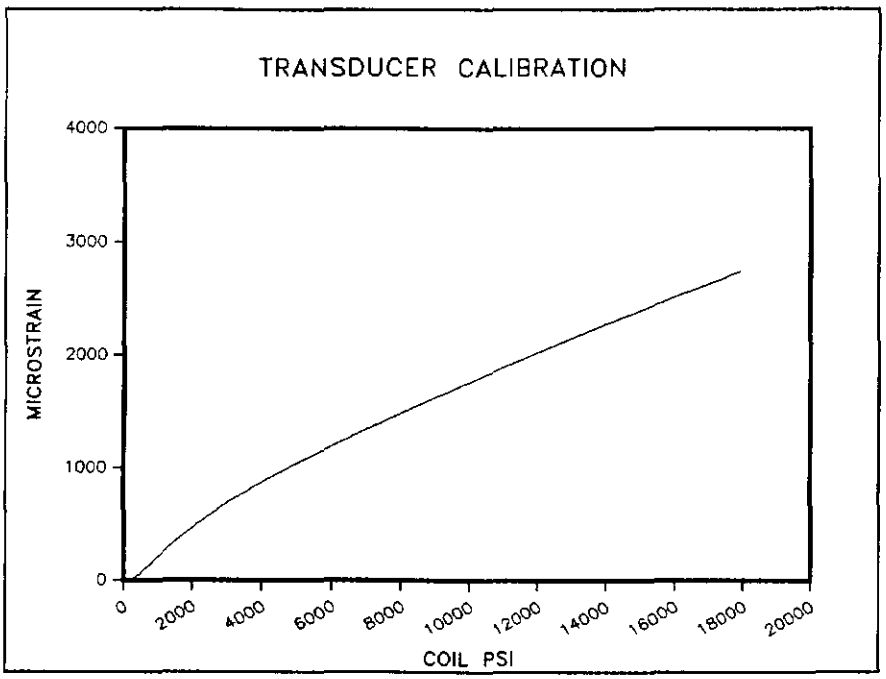

Fig. 6 Calibration of transducer with an uncut Fermilab ten-stack.

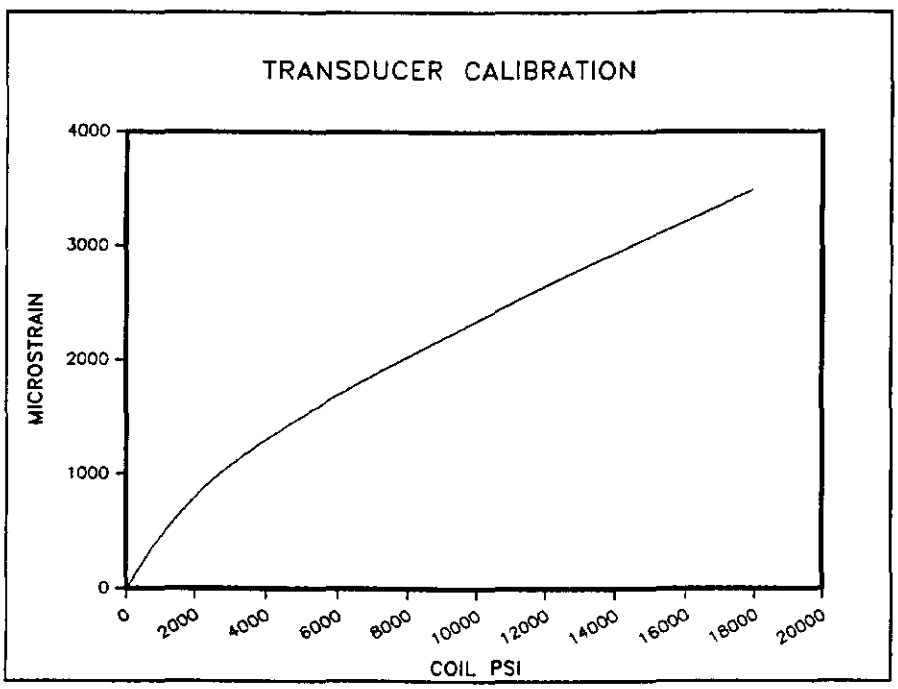

Fig. 7 Calibration of transducer with Fermilab cut ten-stack.

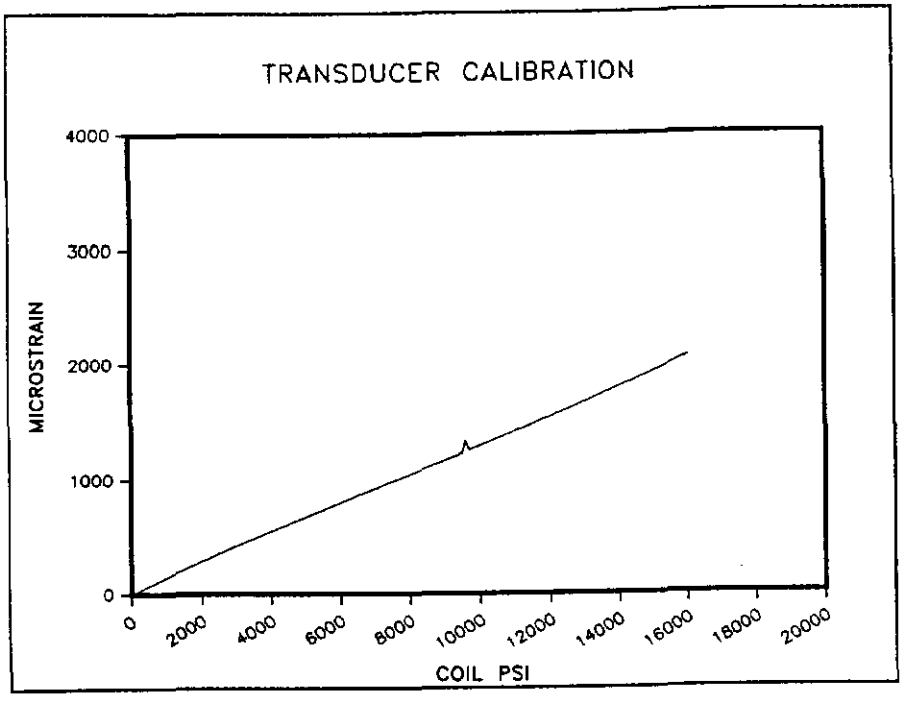

Fig. 8 Calibration of a transducer with BNL uncut ten-stack.

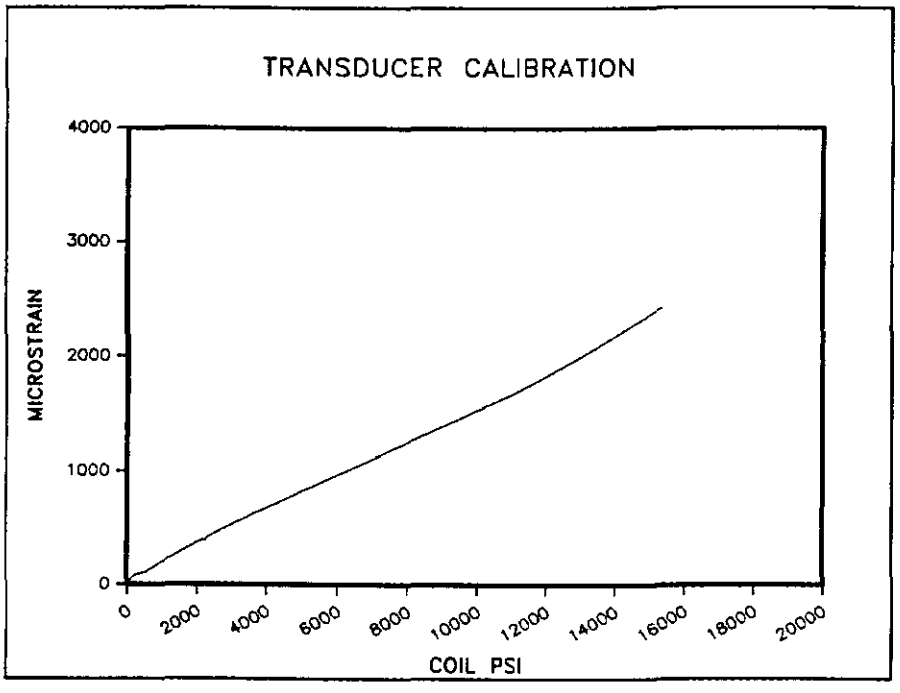

Fig. 9 BNL ten-stack cut to just fit in a calibration fixture.

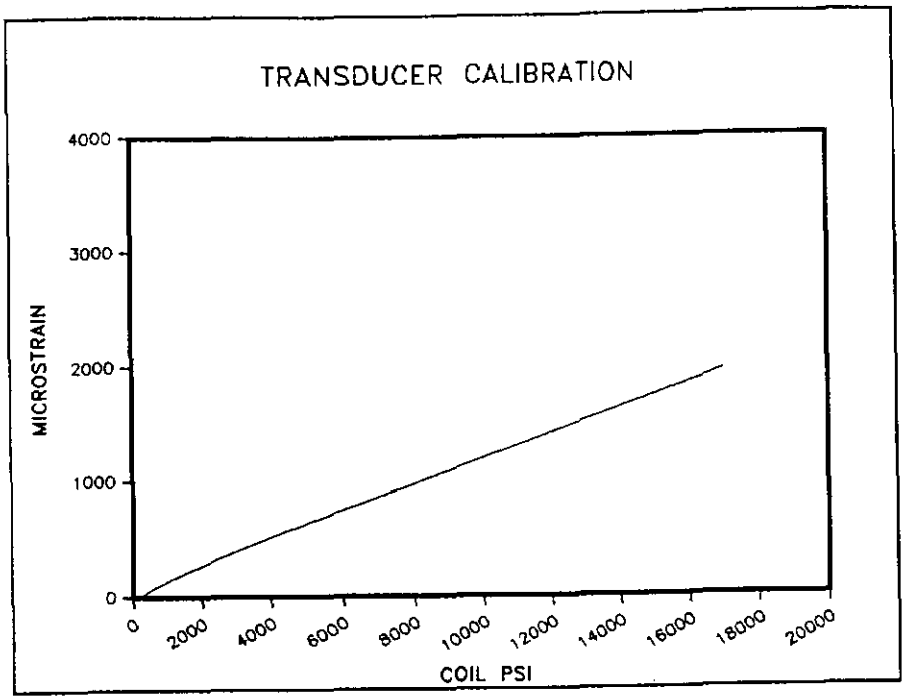

Fig. 10 Current calibration curve of a transducer.

The characteristic curve of a ten-stack should closely resemble the characteristic curve of an actual coil. This difference between the curves is believed to be influencing the low end of the calibration curve. This influence is evident in calibration curves resulting from stiff ten-stacks as opposed to looser ten-stacks. See Figures 2 and 10. The calibration curve of the looser stack does not become linear until higher loads. The opposite case is true with the stiffer stack. This implies that the non linear modulus of the stack causes the non-linearity of the calibration curve at the initial loading. With this fact in mind, characteristic curves were made of deflection versus load of an actual coil and compared to ten-stacks. The analysis of the curves shows that the actual coil became linear at approximately 3000 psi, the BNL stack at approximately 2000 psi, and the Fermilab stack at approximately 4000 psi. See Figures 11, 12, and 13.

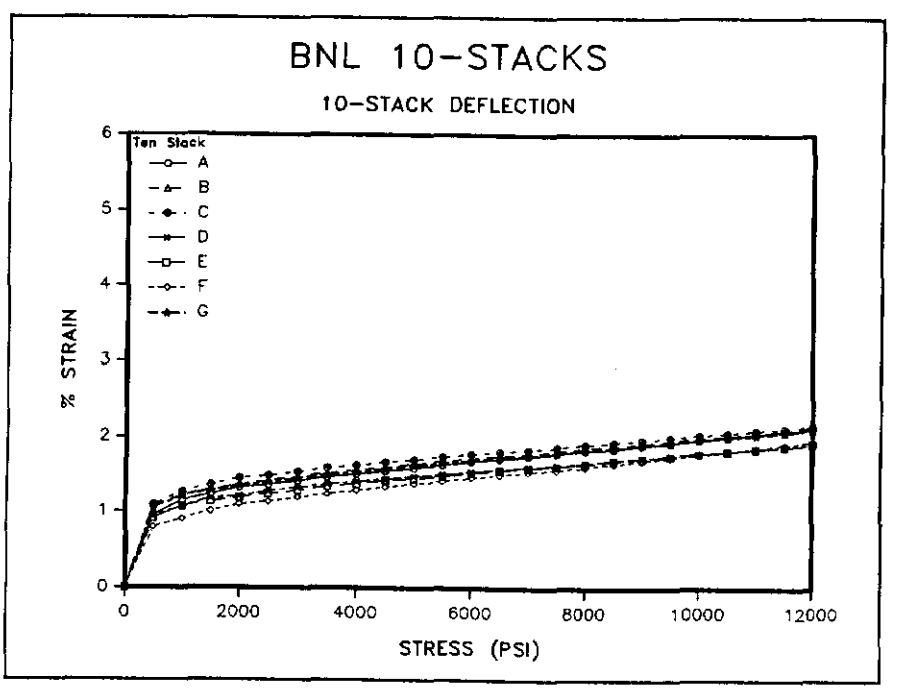

Fig. 11 BNL ten-stacks.

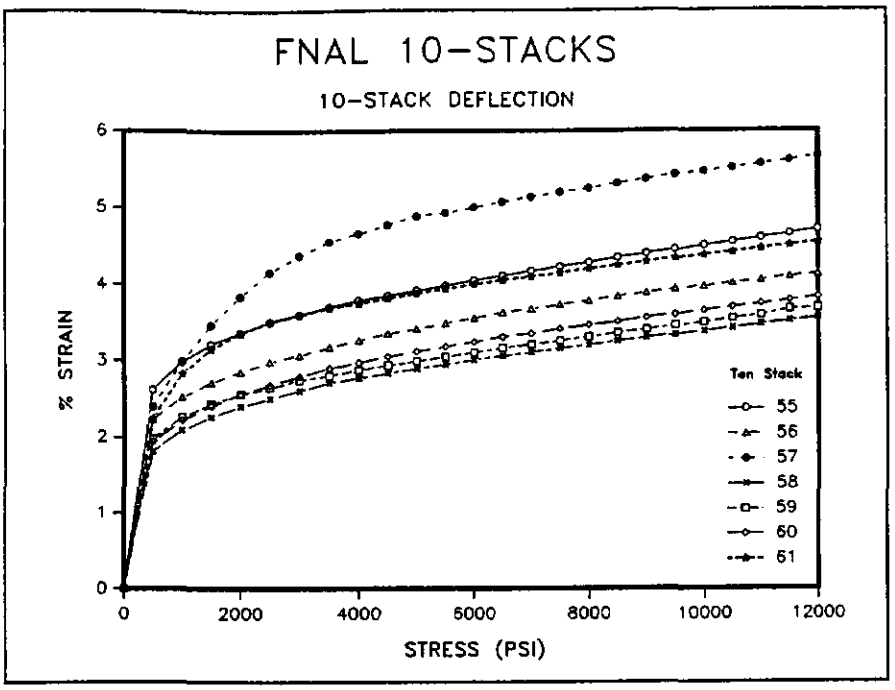

Fig. 12 Fermilab ten-stacks.

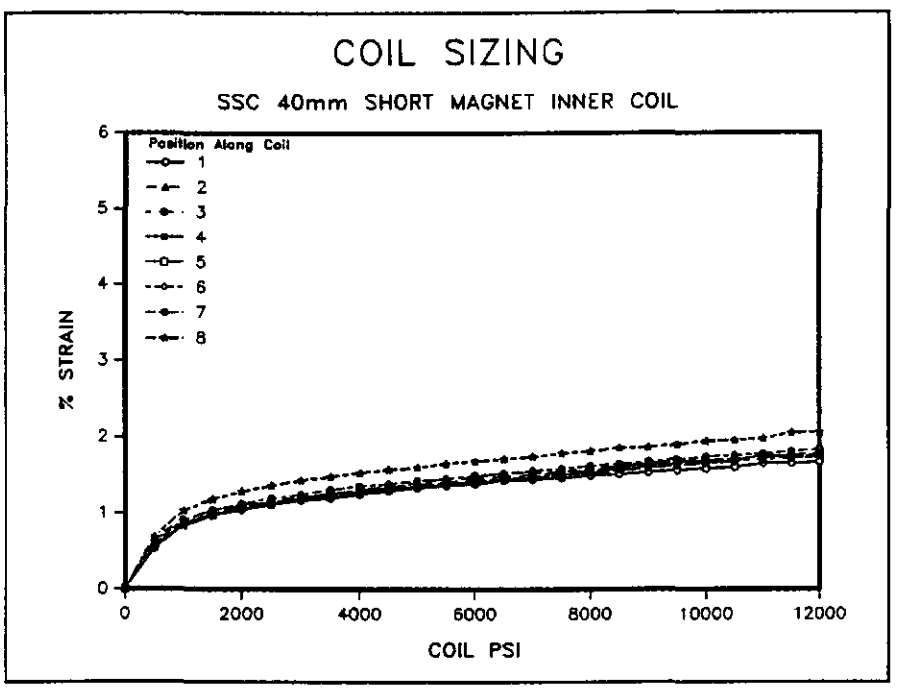

Fig. 13 Coil sizing.

CONCLUSIONS

As a result of these observations, new backing plates must be used for each calibration to avoid deforming the plate. This also implies that a backing plate should be kept paired with a transducer even after calibration up to and including installation in the magnet. Ten-stacks should not be cut and used over. This leads to poor and unrepeatable calibrations.

The data taken during coil sizing is very important. Currently, Fermilab is constructing SSC coils with lower epoxy content in accordance with the current Fermilab ten-stacks. Coil sizing data could be correlated with the calibrated transducers that are going to be used to measure the stresses on that coil. More data of this sort needs to be taken

to determine how to model a ten-stack after a coil. The data gathered from coil sizing could be used to establish an allowable window for the properties of a ten-stack. The stacks could be tested and would have to fit this window to be acceptable.

Table 1 Coil Modulus*

BNL Stack	10-Stack E x 10e-6	FNAL Stack	10-Stack E x 10e-6	FNAL Position	Inner Coil E x 10e-6
A	1.30	55	0.950	1	1.96
B	1.40	56	1.20	2	1.76
C	1.50	57	0.98	3	1.75
D	1.59	58	1.30	4	1.66
E	1.50	59	1.02	5	1.70
F	1.23	60	1.07	6	1.65
G	1.43	61	1.15	7	1.67
				8	1.54
	Mean = 1.42		Mean = 1.1		Mean = 1.71

* = Units of psi

REFERENCE

1. C. L. Goodzeit, M.D. Anerella, and G.L. Ganetis, "Measurement Of Internal Forces In Superconducting Accelerator Magnets With Strain Gauge Transducers," SSC-MAG-R-7312, (1989).