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COIL STRESS MEASUREMENTS ON FIVE 1-m SSC MODEL DIPOLES

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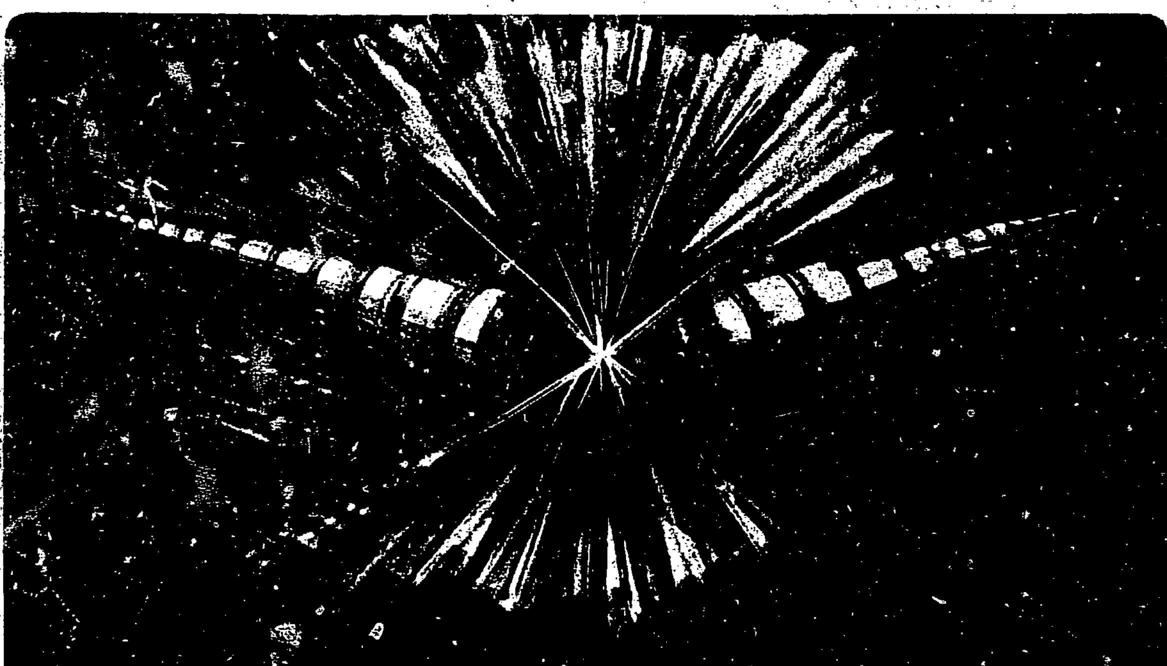

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INTRODUCTION

This note will discuss the results of coil stress measurements made on five 1-m model dipole magnets constructed and tested at LBL. The measurement system is described. A discussion of measurement results and correlation to predictions is given.

MEASUREMENT SYSTEM

Four pressure gages were installed in model magnets C-2 through C-6. The gages are located near magnet centerline. Figure 1 shows a view of the gage arrangement. Each gage consists of four strain gages mounted on an aluminum block and wired in a full bridge. Two gages are oriented in the azimuthal direction and two gages are on unstrained surfaces and provide temperature compensation. Several gage designs were used; earlier models (C-2 and C-3) used a separate aluminum block in a slotted strainless or brass holder (see Fig. 2), models C-4 and following models used one piece gage blocks (see Fig. 3).

The gages were designed to be insensitive to strains normal to the measured direction. Calibration testing of the installed gages showed this was not strictly the case for the outer layer gages. As a result, the outer layer gages have evolved slightly to a present form which is truly insensitive to these normal strains. In any case, the errors incurred are small and apply only to outer layer pressure measurements. The calibration arrangement of installed gages is shown in Fig. 4. It is important to calibrate the pressure gage collar packs in a fixture which holds the collars by the keyways as occurs in a collared magnet.

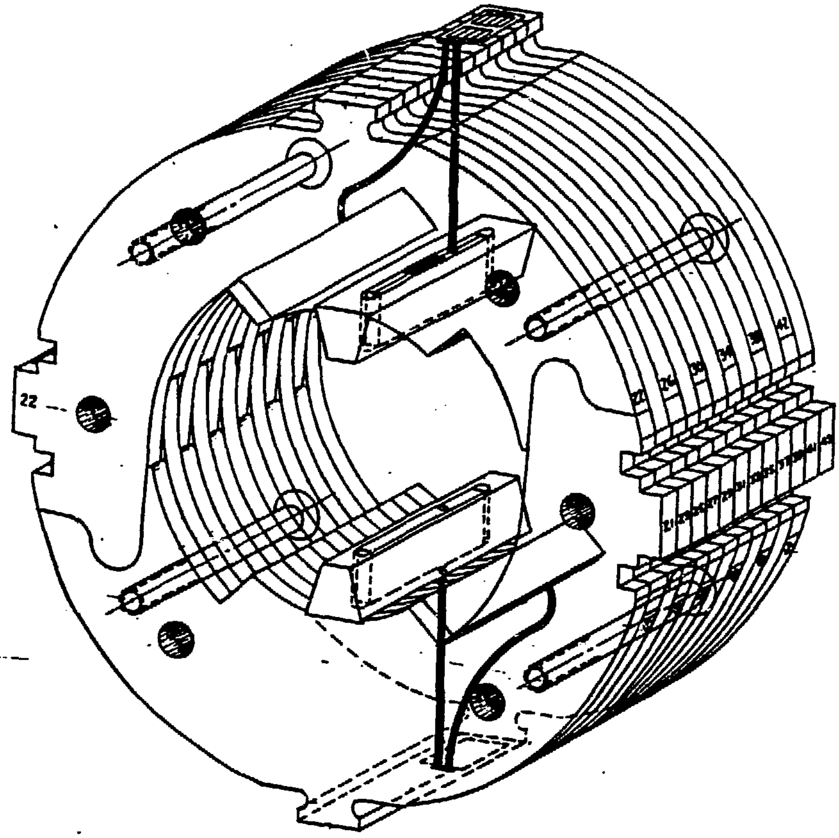


Fig. 1 Pressure Gages Installed in Center Collar Pack.

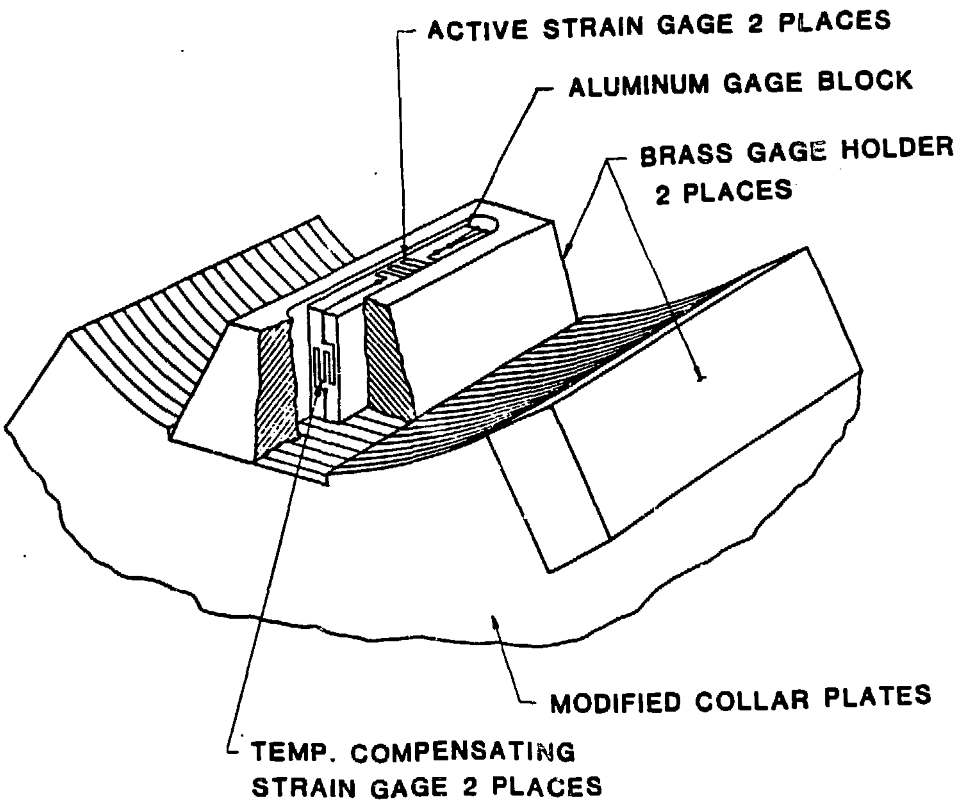


Fig. 2 Slotted Type Pressure Gage

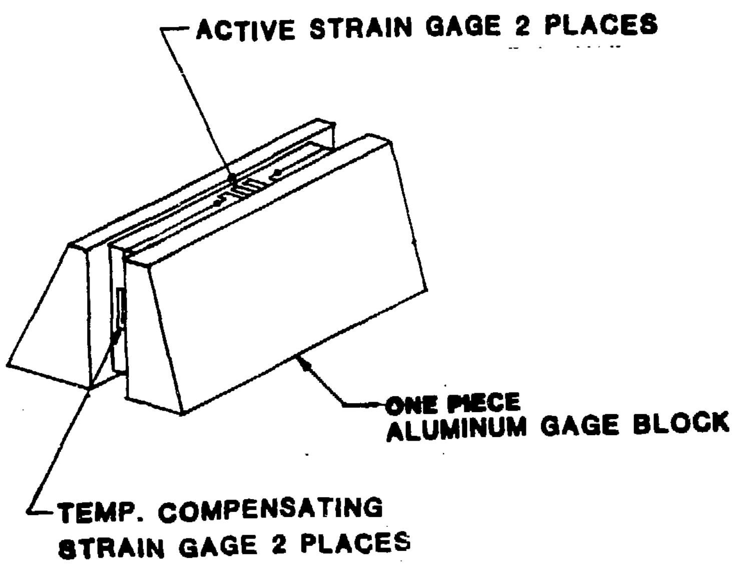


Fig. 3 One Piece Type Pressure Gage

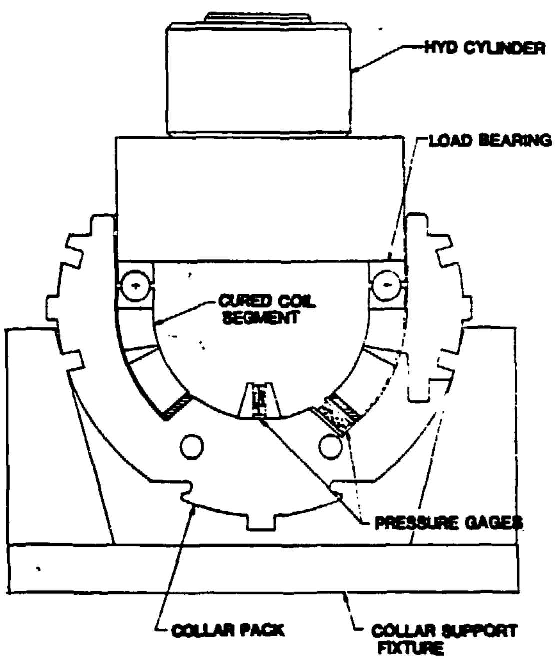


Fig. 4 Pressure Gage Calibration Set-Up for Outer Layer

During calibration, 10 mA current is put across the gage and the voltage is measured. This is illustrated in Fig. 5. Typically, the gage sensitivity is between .3 to .5 μV/psi. After calibration at room temperature, the press gage collar packs are cooled to 80K and the change in output voltage is measured. This offset is then superimposed on the room temperature calibration to produce an 80K calibration curve.

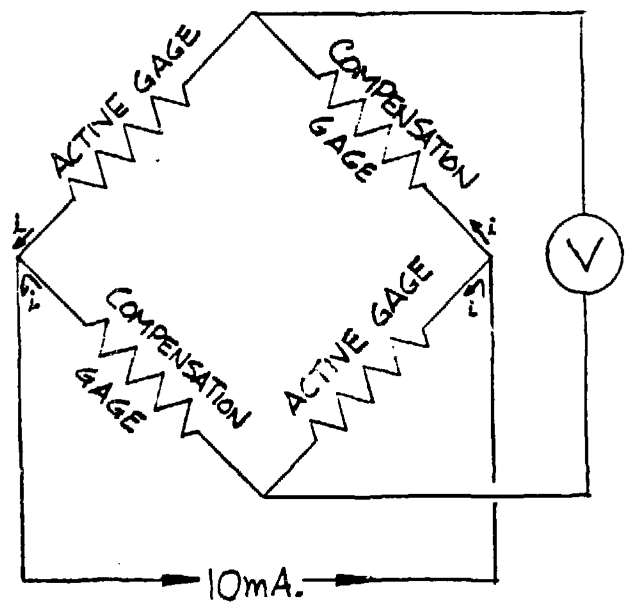


Fig. 5 Pressure Gage Wiring

MEASUREMENT RESULTS

Cooldown

A typical cooldown curve is shown in Fig. 6 for model C-5. The change in coil prestress during cooldown for models C-2 through C-5 is shown in Table I. Data for model C-6 is not available due to a change in construction procedure.

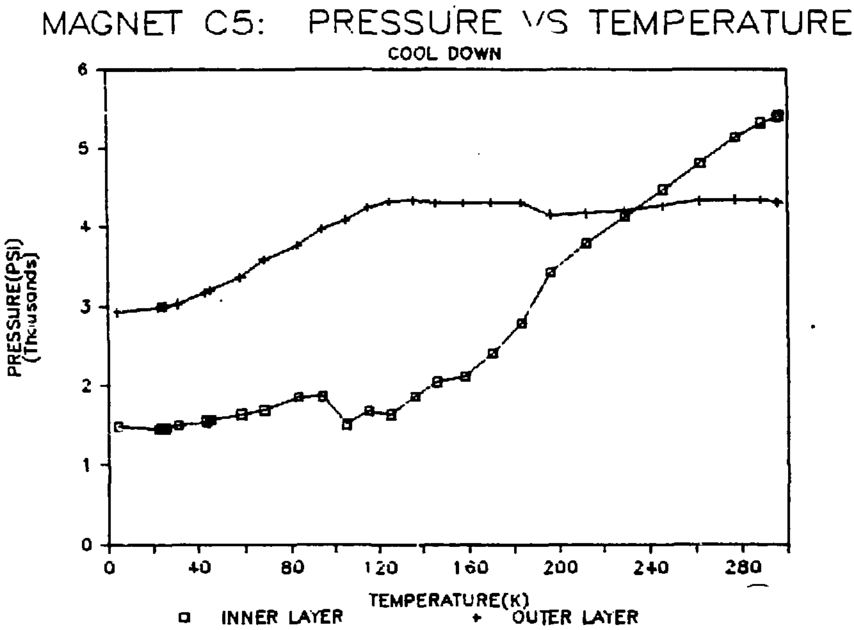


Fig. 6 Pressure During Cooldown for Model C-5

TABLE I

Change in Coil Prestress Between Room Temperature and 4K

Model #	Inner Layer (Kpsi)	Outer Layer (Kpsi)
C-2	-5	-1.5
C-3	+2	+1.0
C-4	-5	-2.0
C-5	-4	-1.5

Note: Model C-3 is collared with 25 mm Aluminum Collars.

Training

The following discussion of coil pressure data applies to all the models tested; model C-5 data is used to illustrate the observations.

Figure 7 through 10 is a series of plots for model C-5 showing the coil pressure to current relationship for the first four training cycles. Coil pressure is measured at the upper or pole conductor. The data plotted for each layer is the average of the two gages in each layer. The inner layer pressure at no current increases slightly after each current cycle starting at 1500 psi (see Fig. 7) and ending at 2000 psi for the fourth cycle (see Fig. 10). This 500 psi upward migration of the pressure curve is not understood, but is exhibited in all the models. It suggests that, during cooldown, the cable near the pole is temporarily pulled away (not separated), and, during cycling, the addition of Lorentz forces enables the inner coil to slip back toward the pole producing the observed rise in pressure. The change of pressure with current will be discussed later. The outer layer behavior is more as expected. During the first four cycles, the pressure curve migrates downward by about 1200 psi. This presumably is due to Lorentz forces plus friction against the collars which prevent the coils from fully reloading the pole when the Lorentz forces are removed.

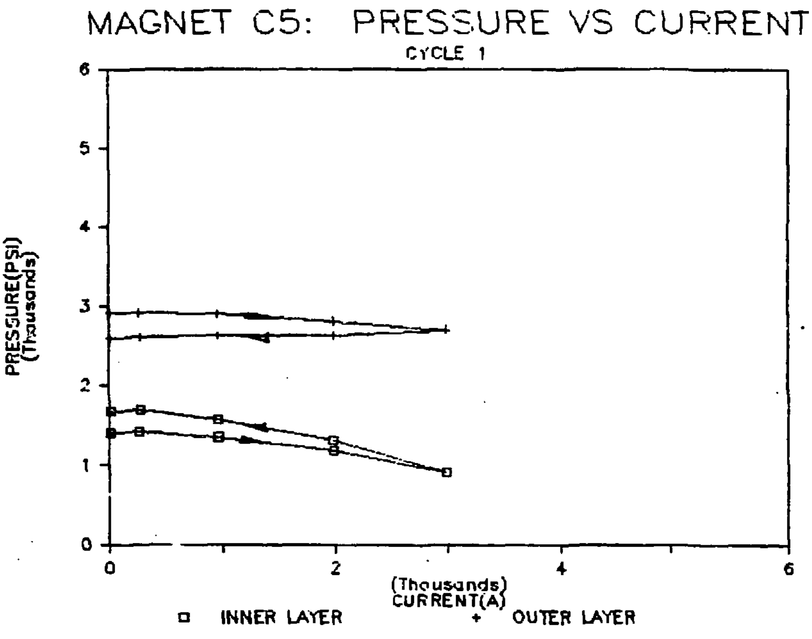


Fig. 7 Model C-5 Pressure to Current for Training Cycle 1.

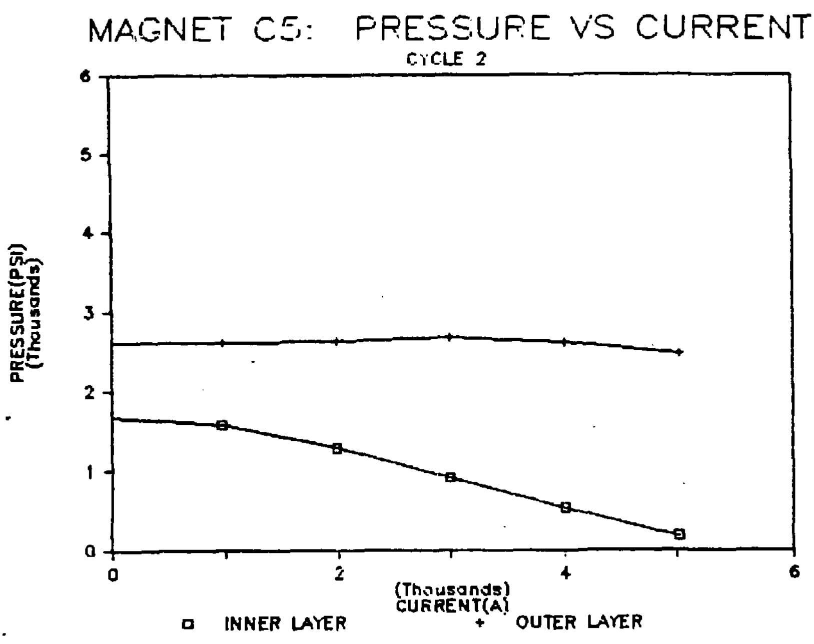


Fig. 8. Model C-5 Pressure to Current for Training Cycle 2.

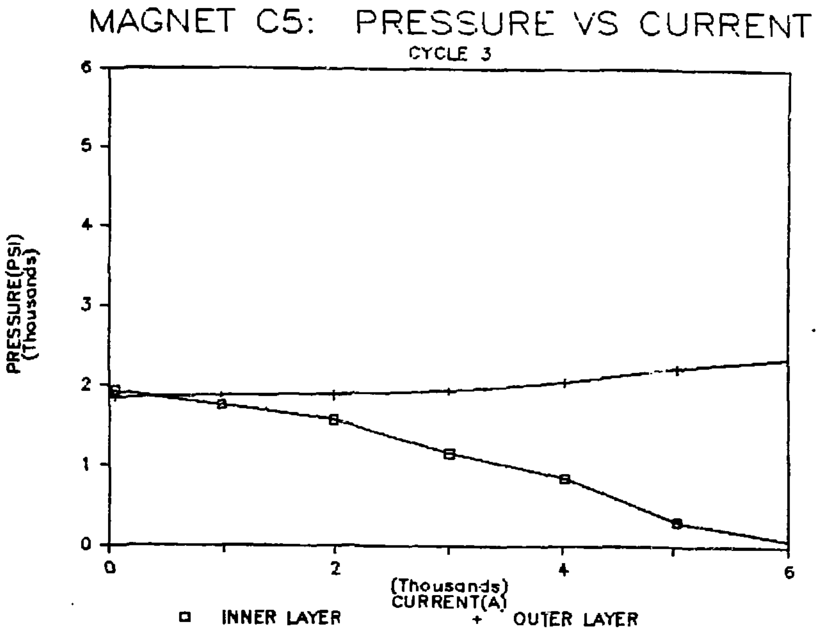


Fig. 9 Model C-5 Pressure to Current for Training Cycle 3.

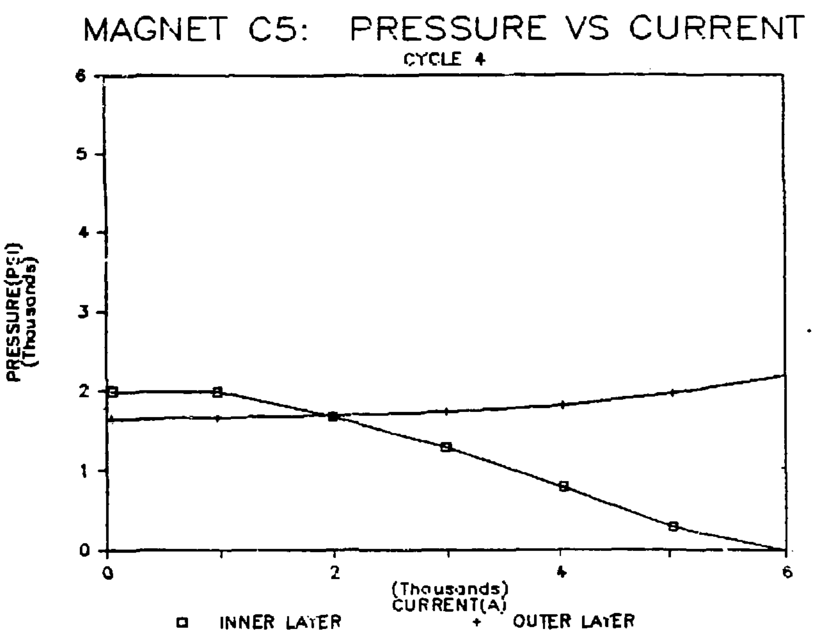
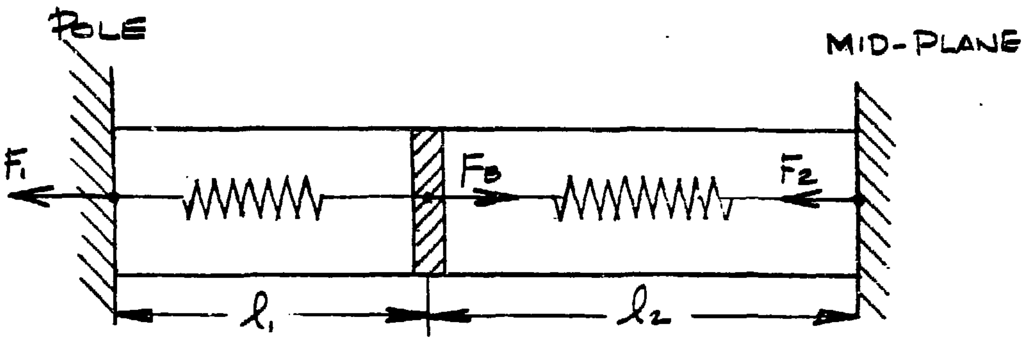


Fig. 10 Model C-5 Pressure to Current for Training Cycle 4.

Predicted and Measured Change of Coil Pressure at 6 Tesla

Below is shown a simplified magnet coil. Only azimuthal forces are shown and friction is assumed to be zero. The collar system is assumed to be rigid.



A force balance on a single conductor with an applied body force, which displaces it by $\Delta\ell$, gives the following:

$$F_B = F_1 + F_2$$

$$F_B = EA\,\frac{\Delta\ell}{\ell_1} + EA\,\frac{\Delta\ell}{\ell_2}$$

$$\Delta\ell = \frac{F_B}{EA\left(\frac{1}{\ell_1} + \frac{1}{\ell_2}\right)}$$

The force, F_1, at the pole is then;

$$F_1 = EA\,\frac{\Delta\ell}{\ell_1}$$

$$F_1 = \frac{EA}{\ell_1}\,\frac{F_B}{EA\left(\frac{1}{\ell_1} + \frac{1}{\ell_2}\right)}$$

$$F_1 = \frac{F_B}{\left(1 + \frac{\ell_1}{\ell_2}\right)}$$

This then gives the force on the coil at the pole due to the body force, F_B, on an element of conductor. The direction is tension as shown. For a precompressed coil, the pole force will appear as a loss of compression (i.e., the tension is superimposed on the precompression).

Substituting the appropriate expression for F_B and integrating for all the elements, the total loss of compression at the pole is 2981 psi and 2404 psi for the inner and outer coils, respectively. For each layer this is 2/3rds of the simple sum of the Lorentz forces.

The measured loss of compression at the pole of each layer for models C-2 through C-6 is shown in Figs. 11 and 12. For the inner layer the loss of pole pressure at 6 Tesla ranges from 67% to 100% of the predicted loss. For the outer layer, the loss of pole pressure ranges from -16% to 63% of the predicted loss. The outer layer behavior is obviously perplexing. Three things may be acting to cause the loss of prestress to be less than predicted; friction against the collar hindering conductor motion away from the pole, poisson or hydraulic effect on the outer layer (the coil bounded by a fixed length will increase in pressure at the pole when pressed on radially by the inner layer), and the elasticity of the collars (for elastic collars, the collars will tend to maintain the total force on the coils - as the force on the inner layer decreases, the force on the outer layer will tend to increase). A series of tests have begun at LBL to understand and measure the contribution of each of these effects.

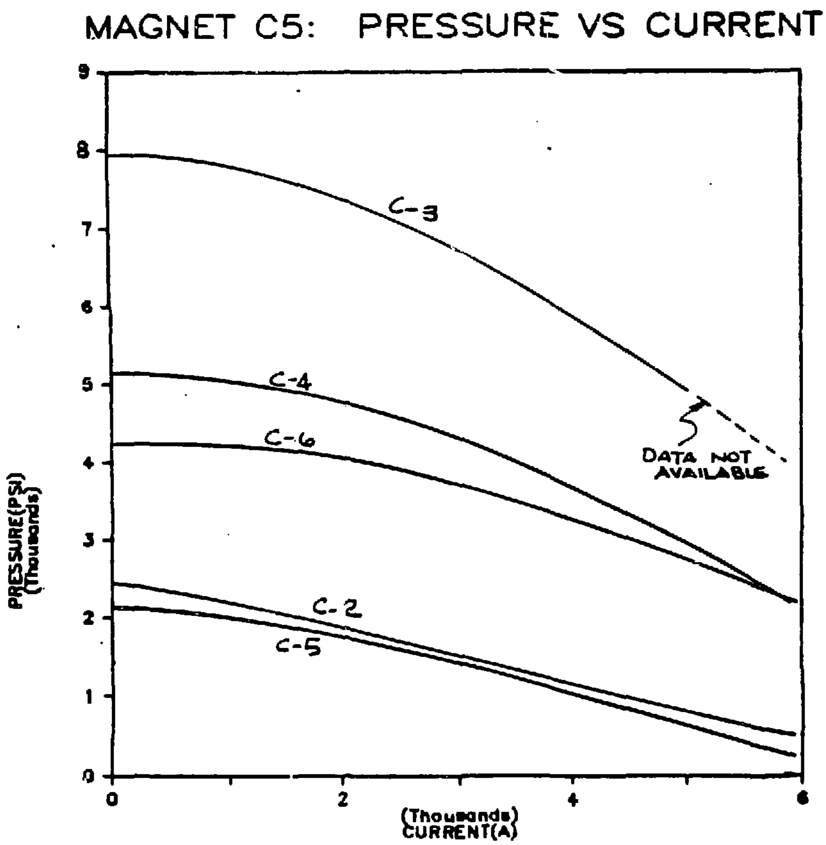


Fig. 11 Inner Layer Pressure During 6th Training Cycle

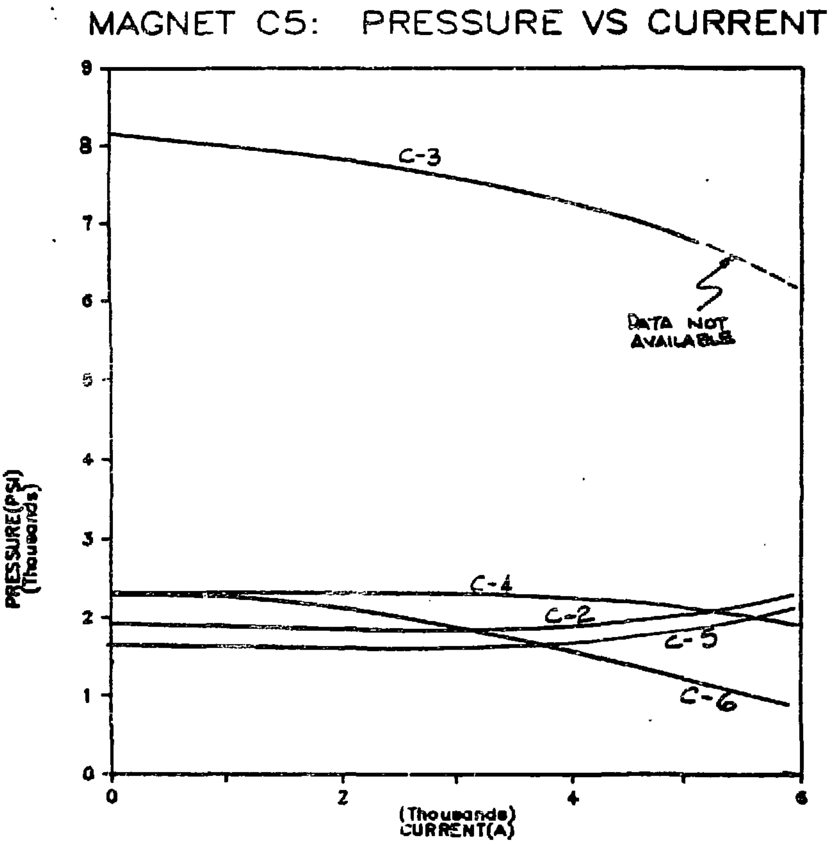


Fig. 12 Outer Layer Pressure During 6th Training Cycle