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Appendix

NONLINEAR PIEZORESISTIVE MANGANIN GAUGE CALIBRATION

Although the piezoresistive behavior of Manganin under hydrostatic pressure is almost linear the nonlinearity in response may be sufficient to cause significant errors for precise experiments. Although the nonlinear behavior would not be expected to be the same for all gauges, in the absence of specific calibration data at multiple fixed pressures it appears reasonable to utilize typical values of nonlinearity obtained by various investigators. The observed range of nonlinear parameters can serve as a measure of the expected uncertainty due to the nonlinear response.

Consider that the pressure is a quadratic function of the relative change in resistance

$$p = a(\Delta R/R_0) + b(\Delta R/R_0)^2, \qquad \text{(A1)}$$

where p is the pressure, ΔR is the change in resistance, R_0 is the original resistance, and "a" and "b" are material constants of the Manganin gauge. For a calibration at a fixed pressure, p_c, the coefficients can be expressed as

$$a = \frac{p_c}{\left(\dfrac{\Delta R}{R}\right) + \dfrac{b}{a}\left(\dfrac{\Delta R}{R}\right)^2}. \qquad \text{(A2)}$$

For fixed b/a, a nonlinear calibration can be established.

Measurements of the nonlinearity in Manganin gauge response have been summarized by R. C. Lincoln.[4] The data are shown in Table A-1.

TABLE A-1

Nonlinearity parameters for Manganin gauges

Source	b/a
Newhall (a)	0.279
Johnson (b)	0.331
Lincoln (c)	0.352
Boren *et al.* (d)	0.600
Zeto *et al.* (e)	0.615
Midpoint between above extremes	0.447

(a) Private communication from D. H. Newhall, Harwood Engineering, to R. C. Lincoln. (b) Private communication from D. P. Johnson, National Bureau of Standards, to R. C. Lincoln. (c) Ref. 4. (d) M. D. Boren, S. E. Babb and G. J. Scott, *Rev. Sci. Instr.* **36**, 1456 (1965). (e) R. J. Zeto and H. B. Van Fleet, *J. Appl. Phys.* **40**, 2227 (1969).

Even though b/a shows a wide range among the various investigators, the actual effect on the predicted pressure is small due to the relatively small values of $\Delta R/R_0$.

We have chosen to use the midpoint, $b/a = 0.447$, between the observed extreme values of 0.279 and 0.615 as a representative value for b/a. For our gauges we found this range of b/a introduced an uncertainty of ±1% in the first pressure derivative of our data. Failure to include a nonlinear effect would have led to bias in the first pressure derivative from 1.3% to 3.8% depending on the gauge. To eliminate this bias it appears best to utilize Eq. (A1) to establish the pressure from the $\Delta R/R_0$ readings.