Group Four Transducers Inc

Electrical Bridge Nonlinearity In Strain Gage Load Cells

One of several and frequently neglected contributors to nonlinearity in strain gage load cells is electrical bridge nonlinearity. It is most notable in column type load cells and contributes quite significantly to nonlinearity in those load cells types. But it is present in other load cells, as well.

A thorough understanding of this effect and its quantification will help to achieve better nonlinearity performance in Group Four load cells.

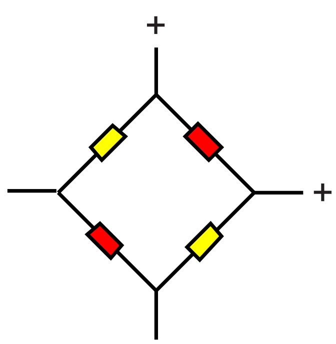
This paper will explore electrical bridge nonlinearity and develop some useful equations.

The Source of Electrical Bridge Nonlinearity:

In *fully active* strain gage bridge circuits, where the absolute value of the four sensed strains are equal, there is no electrical bridge nonlinearity because the bridge excitation currents in the left and right hand legs of the bridge are constant during load application.

The most common and largest form of electrical bridge nonlinearity resides in column type load cells such as the Group Four rocker column which includes two longitudinal strain gages sensing compressive strains and two transverse strain gages sensing the tensile, Poisson strains.

Figure 1:
Strain Gage Bridge Circuit



In FIGURE 1 the bridge current situation is different than in the *fully active* strain gage bridge circuit... The red rectangles represent the compressive strain sensing strain gages and the yellow rectangles the tensile Poisson sensing strain gages. Since the Poisson tensile strains are 0.3 times the compressive strains the absolute value of the four sensed strains are not equal. In fact, the bridge excitation currents in the left and right hand legs actually increase with applied load because the resistance of the compression strain gages decreases more than the resistance of the tension strain gages increases.

The increasing bridge current with applied load causes the sensitivity of the bridge to increase, causing the slope of the loading curve to increase which results in a "concave up" loading curve or negative nonlinearity. The converse would be true if the column were loaded in tension in which case the Poisson gage becomes the compression gage, the bridge current decreases with applied load and the nonlinearity becomes "concave down" or positive.

Quantification of the Electrical Bridge Nonlinearity:

Using the bridge circuit of *FIGURE 1*, an expression for the full-scale electrical output of a typical column type load cell will be developed. The red strain gages sense compressive strains and the resistance of those strain gages decreases with applied load:

[A]

$$R = R_0 - \Delta R$$

The yellow strain gages, the Poisson gages, increase in resistance with load according to the equation below:

[B]

$$R = R_0 + \beta\Delta R$$

where β is the fractional strain reduction.

Treating the two bridge legs as voltage dividers and subtracting the voltage at the signal terminal of the left land leg from the right hand leg results in:

[C]

$$E_{FSO} = \frac{R + \beta\Delta R - (R - \Delta R)}{R + \beta\Delta R + R - \Delta R} = \frac{\Delta R(\beta + 1)}{2R + \Delta R(\beta - 1)}$$

The linear half full scale output signal is simply half of the above:

[D]

$$E_{HSO} = \frac{\frac{1}{2}\left[R + \beta\Delta R - (R - \Delta R)\right]}{R + \beta\Delta R + R - \Delta R} = \frac{\frac{1}{2}\left[\Delta R(\beta + 1)\right]}{2R + \Delta R(\beta - 1)}$$

But the actual half scale output is obtained from equation *[D]* by using half the values:

[E]

$$E_{AHSO} = \frac{\frac{\Delta R}{2}(\beta + 1)}{2R + \frac{\Delta R}{2}(\beta - 1)}$$

Subtracting equation *[E]* from equation *[D]* and dividing that result by the full scale output, equation *[C]*, and multiplying by 100 provides the percentage non-linearity (at half scale) of the partially active strain gage bridge of the column type load cell:

[F]

$$\%N.L. = \frac{1}{2}\left[1 - \frac{2 + \frac{\Delta R}{R}(\beta - 1)}{2 + \frac{1}{2}\left(\frac{\Delta R}{R}\right)(\beta - 1)}\right] \times 100$$

Substituting 0.3 (Poisson's ratio for steel) for β and using a value of 3.4 ohms for the full scale ΔR of the 1000 ohm strain gage results in a nonlinearity value of 0.030 %.

Equation *[F]* may be simplified to make it easier to use by applying the gage factor relationship and using a gage factor of 2.0:

[G]

$$G.F. = \frac{\frac{\Delta R}{R}}{\frac{\Delta l}{l}} = \frac{\frac{\Delta R}{R}}{\mu\varepsilon}$$

And equation *[F]* becomes:

[H]

$$\%\,N.L. = \frac{1}{2}\left[1 - \frac{2 + 2\mu\varepsilon(\beta - 1)}{2 + \mu\varepsilon(\beta - 1)}\right] \times 100$$

This equation is easier to deal with when attempting electrical bridge nonlinearity calculations on load cells with different output levels, e.g., 1 mV/V vs. 2 mV/V.

The form of equation *[H]* changes slightly when the compression gages become the Poisson gages:

[I]

$$\%\,N.L. = \frac{1}{2}\left[1 - \frac{2 + 2\mu\varepsilon(1 - \beta)}{2 + \mu\varepsilon(1 - \beta)}\right] \times 100$$

In this case the polarity of the nonlinearity changes while the magnitude remains the same as in equation *[H]*.

Using Electrical Bridge Nonlinearity to Advantage:

Occasions may arise where a load cell may exhibit a systematic nonlinearity and a correction is desired which can not be accomplished, mechanically. Electrical bridge nonlinearity can be used in such situations.

If the nonlinearity is positive ("concave down") an increasing bridge current with applied load is required and vice versa.

For example, if the nonlinearity on a 2 mV/V load cell is 0.0085 % a β factor of 0.8 will reduce that undesirable nonlinearity to zero.

A table of β factors and their nonlinearity corrections is provided below:

β Factor	Non-linearity Correction
1.00	0.0000
0.90	0.0043
0.80	0.0085
0.70	0.0130
0.60	0.0170
0.50	0.0210
0.40	0.0260
0.30	0.0300

Equation *[H]* or *[I]* can be put into a Solver in Excel or in a good calculator and the required β factor can be calculated, given the required nonlinearity correction.

It should be noted, however, that electrical bridge nonlinearity correction cannot be applied to planar beams and winged planar beams which are gaged on opposite sides. However, when gaged on one side, planar beam or winged planar beam load cells can be linearized by simply moving the point of load application toward the tension gages to reduce positive non-linearity and toward the compression gages to reduce negative nonlinearity.

Similar nonlinearity corrections can be made on diaphragm load cells and on any beam constructions containing a fold-back arm for load application.

Conclusions:

It has been shown that electrical bridge nonlinearity errors are not insignificant and are as high as 0.030 per cent on 2 mV/V rocker column load cells. Fortunately, this inherent electrical bridge nonlinearity is offset by another inherent nonlinearity, the "area change" effect which will be covered in another paper.

The net inherent nonlinearity of column type load cells can be virtually eliminated with semiconductor strain gage linearization which is the subject of yet another paper.

It has also been shown how electrical bridge nonlinearity can be used to linearize load cells which are not subject to linearization by mechanical means.

Mechanical linearization of certain load cells will be covered in another paper.

HARRY E. LOCKERY MEE, PhD
harryl@group-4.com
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